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# GLACIERS AND GLACIATION OF ALASKA*

RALPH STOCKMAN TARR

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INTRODUCTION.—Notwithstanding the great area of Alaska, the ruggedness and inaccessibility of a large part of the glaciated region, and the briefness of the period of exploration, we are already in possession of a large body of fact with regard to the glaciers and

NOTE.—Shortly after the manuscript of this address was completed Professor Tarr suddenly died, and the proof of the text and illustrations has been read by Professor Lawrence Martin.

An appreciation of the work of Professor Tarr in geography and for the Association will be incorporated in Volume III of the ANNALS.

EDITOR.

* Presidential Address delivered before the Association of American Geographers, December 29, 1911, and printed in Science, N. S., vol. XXV, 1912, pp. 241-258.

glaciation of our northern territory.* The researches of Wright,[1] Russell[2], Reid[3], Gilbert[4], Davidson[5], Dall[6] and others have given us much valuable information concerning the coastal region; and the many expeditions by Hayes[7], Brooks, and various other members of the United States Geological Survey[8] have added materially to this knowledge, and have extended the area of observation to the interior. Thus, even though there is yet much to learn, the knowledge that we now possess is sufficient to warrant a discussion of the general phenomena of Alaskan glaciation; and since this is the object that has been most in my mind during the past six years, it has naturally appealed to me as the most fitting topic for the presidential address which I am called upon to give.

THE EXISTING GLACIERS.—*Condition of the Existing Glaciers.*— Alaskan glaciation is, and has been, of the mountain type. That is to say, mountain snow fields have shed into mountain valleys, and through these the glacier ice has flowed to lower levels; in some cases even to the sea. Numerous glaciers, and in former times a still greater number, have flowed beyond their valleys and spread out fan-shaped at the mountain base, giving rise to the type of piedmont glacier which

* The personal field work upon which this address is in part based was done in 1905 and 1906 under the auspices of the U. S. Geological Survey; and in 1909 and 1911 under the auspices of the Research Committee of the National Geographic Society. To both of these bodies acknowledgments are due for the generous financial support given. The last two expeditions have been under the joint leadership of Professor Lawrence Martin and myself; and I wish especially to acknowledge my indebtedness to my colleague in two seasons of work, who was also an assistant on the first expedition. We have worked and observed together and have freely discussed all problems which have arisen. The results of our joint work are used in this address, as are also the results of other students of Alaskan glaciation.

[1] Wright, G. F., The Ice in North America, New York 1891, chapter III, pp. 36-66.

[2] Russell, I. C., An Expedition to Mount St. Elias, Alaska. Nat. Geog. Mag., vol. 3, 1891, pp. 53-203; Second Expedition to Mount St. Elias, Thirteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1892, pp. 1-91.

[3] Reid, H. F., Studies of Muir Glacier, Alaska, Nat. Geog. Mag., vol. 4, 1892, pp. 19-84; Glacier Bay and its Glaciers, Sixteenth Ann. Rept. U. S. Geol. Survey, pt. 1, 1894-95, pp. 415-461.

[4] Gilbert, G. K., Glaciers and Glaciation, Harriman Alaska Expedition, vol. III, New York, 1904.

[5] Davidson, G., The Glaciers of Alaska, Trans. and Proc. Geog. Soc. of the Pacific, vol. III, series II, June, 1904, 98 pp.

[6] Dall, W. H., U. S. Coast Pilot, Pacific Coast, Pt. I, Alaska, Washington, 1883; Alaska and its Resources, Boston, 1887.

[7] Hayes, C. Willard, An Expedition through the Yukon District, Nat. Geog. Mag., vol. 4, 1892, pp. 117-159.

[8] Mainly published in Annual Reports, Bulletins and Professional Papers of the U. S. Geological Survey.

Russell has made known to us through his studies of the Malaspina Glacier.

The main region of existing glaciers occupies a roughly semicircular area sweeping from the southern boundary of Alaska, northward, westward and southwestward, toward the Aleutian islands. From either end of this zone both the number and the size of the glaciers increase, and the elevation of their termini decreases, attaining maximum development near the center of the semicircle that surrounds the head of the Gulf of Alaska. Altogether there are at least forty-seven tidal glaciers in this zone, the southeastern-most being the Le Conte Glacier, just north of Wrangell, and the westernmost the McCarty Glacier on Kenai peninsula. Toward the ends of the glacier zone there are few and scattered instances of tidal glaciers; but in the central part of the zone they are numerous, and, where topographic conditions favor, are close together. Thus in Glacier Bay there are at least twelve tidal glaciers; in Yakutat Bay three; and in Prince William Sound twenty. (See Plate I).

How many glaciers there are in this coastal area cannot be even approximately estimated; but, counting large and small, tributaries and main ice streams, they are certainly to be numbered by the thousand. These vary in size from tiny ice masses in cirques, to valley glaciers two or three miles in breadth, and thirty or forty miles in length; and up to the great Malaspina Glacier whose area is estimated to be 1,500 square miles. From the Kenai peninsula to Cross Sound a very large proportion of the seaward face of the mountains is covered with snow and ice, and glaciers exist in a majority of the valleys, filling most of the larger ones. From Controller Bay to Cross Sound a succession of piedmont glaciers and expanded bulbs of individual glaciers spread out between the mountain base and the sea. A journey along this coast is, therefore, a constant glacial panorama.

*Distribution of Existing Glaciers.*—The mountains which fringe the Alaskan coast as a continuous barrier, as far west as Cook Inlet, attain their greatest elevation in the St. Elias-Fairweather Range where peaks rise 12,000 to 15,000 feet, 18,000 feet in Mount St. Elias, and 19,540 feet in Mount Logan. Here, naturally, the glaciers are largest, for from this central area the general elevation, as well as the heights of the peaks, diminishes toward both the southeast and the west.

Back from the coast, and roughly parallel to the curving mountain barrier around the head of the Gulf of Alaska, is another lofty range, sweeping northward from the Aleutian peninsula, then eastward and southeastward. In its highest part, called the Alaska Range, are numerous lofty mountain peaks, including Mount McKinley (20,300 feet), the highest mountain in North America. Between this

interior range and the coastal mountains is a broad depression occupied by Cook Inlet in the south and the Copper River Basin in the east; but in the extreme east the area between the two mountain ranges is mainly occupied by the great volcanic group known as the Wrangell Mountains, whose peaks attain elevations of from 14,000 to 16,000 feet.

Naturally these lofty mountains of the interior are also the seat of numerous and large glaciers. But neither here, nor on the inner face of the coastal mountains, is there so full a development of ice and snow as along the coast. The snow line is higher, the glacier ends are all necessarily well above sea level, and the piedmont type of glacier is absent. The glaciers are essentially confined to the mountain valleys, though some extend to the mouths of the valleys, and a few spread slightly beyond them. It must not be inferred that the glaciers of the interior are insignificant either in size or in number; merely that they suffer in comparison with their larger neighbors nearer the sea. Were they the only glaciers of Alaska they would themselves attract wide attention because of their number and size. Besides being dwarfed by comparison with the coastal glaciers, these in the interior have the disadvantage of remoteness and relative inaccessibility. They are, therefore, far less well known than the glaciers of the coast.

The difference between the glaciers on the two sides of the coastal mountains may be typically illustrated by the Valdez-Klutena system, two glaciers which descend in opposite directions from a common divide in the Chugach mountains, at an elevation of 4,800 feet. The Valdez Glacier, descending on the seaward side of the mountains, is nineteen miles long and ends at an elevation of two hundred and ten feet, while the Klutena Glacier descending toward the interior is only six miles long and ends at an elevation of 2,000 feet. A similar difference is observed in the Nizina and Chisana glaciers, which descend from a common divide at an elevation of 8,000 feet in the Wrangell Mountains, the former descending on the side facing the sea and therefore being much longer than the Chisana Glacier which flows toward the interior. The total length of the two ice streams is about forty-seven miles.

Beyond the Alaska Range, although there are numerous mountain and plateau areas of considerable elevation, lying far to the north, there is a general absence of existing glaciers, the only exceptions known being within the Arctic Circle, in the Endicott Mountains (5,000-8,000 feet). Here, in the summer of 1911, Philip S. Smith and A. G. Maddren[b] observed a number of small valley glaciers.

*Explanation of the Distribution of the Glaciers.*—The distribution of glaciers in Alaska is not difficult to explain. That they are so

[b] Personal communications to the author.

extensively developed along the seaward face of the coastal ranges is plainly due to the fact that the prevailing winds are from the ocean and that in blowing over the warm waters of the Gulf of Alaska, a large amount of vapor is moved forward and precipitated in the form of snow upon the lofty mountain barrier. It is where the coastal barrier is most complete and highest that the snowfall is heaviest and the development of glaciers greatest. The amount of precipitation varies greatly, records of from 100 to 190 inches having been obtained at stations along this coast; but there is no knowledge as to the precipitation among the lofty mountains, except that it is very heavy and mainly in the form of snow.

In a region where from ten to forty feet of snow falls each year at sea level, there must be exceedingly heavy snowfall at elevations where the precipitation is all in the form of snow. As an indication of the vast snowfall among the mountains, reference may be made to Schrader's observation of from eight to twelve feet of snowfall on Valdez Glacier during a week late in April and early in May, 1898. By such heavy precipitation the snowline is depressed to levels of 2,500 to 3,500 feet on the seaward face of the mountains, and to even lower levels back in the mountains where the local climate is cooled by the chill of the surrounding areas of snow and ice.

Since the damp winds precipitate so much vapor in crossing the mountain barrier, there is a deficiency of precipitation on the inner slopes of the mountains and on the ranges beyond. Moreover, such winds as sweep into interior Alaska from either the Arctic Ocean or Bering Sea bear but a limited vapor burden, since the water of these seas is cold in summer and more or less completely ice-covered in winter. Records at Eagle give a rainfall of only 11.35 inches; but the precipitation is doubtless higher toward the west and in the lofty mountains.

The winters of the interior are prevailingly clear and cold with moderate snowfall,—for example only two or three feet of snow fall in the Copper River Basin; but in summer the temperature is so high that the snow quickly melts, even well up on the mountain slopes. Thus, even in the neighborhood of the Arctic Circle a plateau from 3,000 to 6,000 feet in elevation, is completely free from snow in summer as is also a large portion of the Endicott Mountains; and, whereas the snowline on the seaward face of the St. Elias range is about 3,000 feet, it is more than twice as high as that in the interior three or four hundred miles further north. The exact elevation of the snowline in the interior cannot be stated, and indeed it must vary greatly from place to place. In general, however, it is above 6,000 feet.[10]

[10] Oscar Rohn (Twenty-first Annual Report U. S. Geological Survey, Pt. II, 1899-1900, p. 413) states that on September 1st the snow line was 7,500 feet in one part of the Wrangell Mountains, and was then descending.

This rise in the snow line toward the north is interesting as showing how important the element of precipitation is. The snow line is lower and the glaciers are larger where the mean annual temperature is high and the precipitation is heavy than in the much colder climate further north where, however, precipitation is light and the short summers are warm. A similar variation is noticed in the coastal mountains where the snow line is considerably higher along the inner fiords than on the outer coast where the precipitation is heavier. It is to be noted, however, that in the latter place not only is there a greater depth of snow to be melted, but in the neighboring lofty mountains there are broad expanses of snow and ice which serve to retard summer melting.

In the distribution of its glaciers Alaska presents a striking contrast to that part of Europe in the same latitude. There are no glaciers in southern Scandinavia, in the latitude where, in Alaska, the glaciers are largest; and while in Norway there is an increase in glaciation northward, in Alaska there is a decrease. In Norway the influence of latitude is permitted to exert its normal effect; but in Alaska the influence of latitude is effectually counterbalanced by variation in topography and in the vapor content of the air. This contrast may have some significance in the explanation of the development of extensive ice sheets in northwestern Europe and northeastern America, while northern Asia and northwestern North America, in the same latitude, were free from continental glaciation.

*Ice Flooded Valleys and Through Glacier Systems.*—Only by individual description of a large series of instances would it be possible adequately to portray the varied characteristics of the Alaskan glaciers. As in the Alps, Caucasus, and Himalayas, the valley glacier is the normal type, but with many variations in form, size and rate of motion. From the lofty peaks a series of radiating glaciers usually spread outward; but throughout much of the mountain area there is a complex of ramifying glacier systems. Nowhere is there a development of the ice cap condition such as is found in Norway, Spitzbergen and Iceland, for the mountains are so lofty and rugged that the valley slopes serve to drain away the surplus snow that falls upon the steep mountain sides.

Still the snowfall is so heavy, especially near the coast, that, in the process of drainage, the valley systems are deeply filled with ice, in spite of the ruggedness and high elevation. In the area of greatest glacier development, in the St. Elias region, the extent of snow and ice is so great as to have led Russell to speak of it as "a vast snow-covered region, limitless in expanse, through which hundreds and perhaps thousands of barren, angular mountain peaks projected," and to compare it to the "borders of the great Greenland ice sheet." How

deeply these vast glacier systems fill the valleys we have no means of telling; nor can we even estimate the aggregate length or area of the maze of ice streams that flood the mountain valleys. In a region where dozens of glaciers are known to have lengths of from twenty-five to forty miles, it cannot be doubted that the aggregate length of the ice streams is thousands of miles, and that the total area of snow and ice amounts to tens of thousands of square miles.

Although the vast bulk of ice that is slowly draining away the snow that falls among the Alaskan mountains maintains the valley glacier condition rather than developing an ice cap, it gives rise to an intermediate condition, as Russell's description intimates. That is, although the mountain summits are not flooded, the valleys are.

For example, one may start from Yakutat Bay and traveling up one of the large glaciers, rise above the snowline by a moderate grade and finally reach a flat, snow-covered divide, beyond which, also with moderate grade, a descent leads down a glacier flowing in the opposite direction. Or, to the right or the left, also over flat, snow-covered divides, an easy route is open down other glaciers. In this way one may travel for scores of miles, going from one valley to another and from one glacier to another, but crossing only broad, flat snow divides. So deeply is the region submerged by ice that both the valley bottom topography and the valley head divides are so smoothed out as to give rise to a continuous, connected glacier system with drainage in different directions from flattish divides; but both the divides and the glacier distributaries from them are walled in by steeply rising mountains, each portion of the system having the characteristics of the valley glacier. For such a complex I have proposed the name—*through glacier system.*

The through glacier condition is rendered possible by the presence of low divides, and it is believed that, in general, these have originated during an earlier period of more intense glaciation when the snow and ice accumulated to much greater depths than now and flowed across the divides, lowering them by glacial erosion.

In its main essential characteristics, even the through glacier system belongs in the class of valley glaciers; and the valley glacier phenomena in Alaska are in the main the same as those with which we are already thoroughly familiar from the studies of glaciers in the Alps, Himalayas and other mountain regions. As compared with those of the Alps, the larger valley glaciers of Alaska are far greater, and this naturally introduces corresponding differences in form and behavior; but these are differences in detail rather than in underlying principles, and may therefore be dismissed.

At their ends some of the Alaskan glaciers present features not found in the Alps, notably the termination in tidal cliffs from which

icebergs are discharged, and expansion on the land to form piedmont bulbs and piedmont glaciers. At a period of former expansion of glaciers, the piedmont condition was present in the Alps also; and the present Alaskan glaciers are more comparable with those expanded Alpine glaciers than with their shrunken descendants of to-day.

*Development of the Cascading Glacier.*—As in other mountain regions, the present day Alaskan glaciers, though very large, are mere remnants of a former far greater system, occupying the lower levels of valleys which were profoundly deepened by erosion when the former greater ice masses occupied them. Accordingly, the surface of the present day glaciers, in the main valleys, is very often well below the level of the surface of the tributaries, which therefore descend with steep slope at their lower ends. There is every gradation, from the accordant junction of tributary and main glaciers, to the ice step, or "bench," where the two join; to the cascading descent of the tributary as it joins the main ice stream; and to the former tributary, now cut off from junction with the main glacier, but cascading toward it in its lower portion, where it passes out of its hanging valley and descends the steepened valley slopes in a series of broken steps like a great frozen waterfall. This condition is so well developed in Alaska, and is so widespread and so characteristic both in form and cause, that the descriptive name *cascading glacier* has been proposed for it.

*Development of the Ablation Moraine.*—Glacial erosion, which has produced extraordinary topographic change in the Alaskan mountains, has among other things given rise to very steep valley walls. Such steep slopes, produced by ice erosion during the higher stage of the glaciers, are now, on exposure to the air, in a state of instability under the attacks of the agents of subaerial denudation. Therefore, they weather rapidly, and from them rock falls and avalanches frequently descend. This rock, mixed in the snow out of which the glacier is made, and spread out over its surface, is concentrated by ablation in the dissipator until the ice surface may become completely covered by a sheet of moraine, to which the name *ablation moraine* has been given. It is naturally upon the lower ends of the glaciers that the ablation moraine is most extensively developed, but in some instances, it extends far up the valleys, almost or quite to the snowline. Then the valley glacier looks so little like an ice stream that it may not be recognized as one by the casual observer; and on some of the Alaskan maps such glaciers have found no place.

Since only a portion of the Alaskan glaciers bear ablation moraine it is evident that special conditions are demanded for its development. It is best developed on those ice tongues with steep walls and steep heads, whose width is not too great for avalanches to spread

out well toward the middle, and whose valley walls are of a friable rock. In proportion as these conditions vary, the extent of the moraine sheet also varies. Normal weathering and the spread of the falling rock through the snow fields and over the ice tongues are undoubtedly sufficient to account for the formation of a sheet of ablation moraine; but the excessive development of such moraine in some portions of the Alaskan region, may perhaps be due in part to the aid which earthquake shaking gives in the downthrow of avalanches from the glacier valley walls. When a glacier bearing a sheet of ablation moraine has melted away, it leaves not only a deposit of till with scratched stones, but overlying this a sheet of coarse, angular fragments and weathered materials. Such deposits are to be expected in mountain regions of former glaciation.

*Influences Modifying Rate of Recession of Glaciers.*—The ablation moraine is one of the factors influencing the position and rate of recession of glacier fronts: another factor is the position of the front,—whether on the land or in the sea; for in the latter case recession is far more rapid and active than in glaciers ending on the land. For example, in the St. Elias region, while the Guyot, Seward, Marvine, Lucia, Yakutat and other glaciers that end on the land have spread out from one to twenty miles beyond the mountain front, the great, rapidly-moving, tidal Hubbard Glacier, near by, ends at the head of Disenchantment Bay, ten miles or more back among the mountains. Both tidal and non-tidal glaciers are exposed to surface wastage by melting and evaporation; but the tidal glaciers are further exposed to the effective attack of the salt water which quickly removes the ice fragments that fall into it. Therefore, other things being equal, the tidal glacier will naturally terminate farther back among the mountains than non-tidal glaciers of similar character.

Glaciers advancing into rivers are also actively attacked, as is illustrated by the Childs and Miles glaciers in the Copper River Valley, and by glaciers in the Alsek Valley. To a lesser degree the same tendency to more rapid retreat is present in glaciers that terminate in lakes, as the Yakutat Glacier does.

Among ice tongues ending on the land there is great difference in the rate of wastage according to exposure and elevation; but even more important is the protective influence of the cover of ablation moraine. This finds best illustration in those glaciers which spread out fan-shaped at the mountain base, attaining a state of stagnation or semi-stagnation along their margins. Here, near sea level, in a rainy, temperate climate, wastage by ablation would normally be active, and if the ice supply failed the glaciers would rapidly recede. But the sheet of ablation moraine that develops serves as a blanket against both melting and evaporation, and the rate of wastage so decreases with increase in thickness of the morainic cover that there

finally comes a condition of almost complete protection. When the moraine cover is no longer subject to frequent undermining and slumping, vegetation finds a foothold, and ultimately even a mature forest may spread over the moraine that blankets the ice. Glacier recession under such conditions almost ceases and an ice terminus may remain for scores of years without notable change, even though ice supply is completely cut off.

In view of the fact that a protected ice terminus may remain so long in one position, it follows that the piedmont condition is not necessarily proof either of recent expansion or of a continuance of ice supply after expansion. Indeed, there is reason to believe that the piedmont glaciers, and the piedmont bulbs of individual glaciers in Alaska have been formed by expansion at entirely different periods. In some the supply is still being maintained and the ice terminus is kept in place by the essential balance between supply and wastage. This seems clearly to be the case in the greater part of the Malaspina Glacier; but elsewhere there is evidence that the expansion occurred during an earlier period of advance, and that the ice supply has long since been withheld. This is true of the piedmont bulbs of Galiano and Lucia glaciers, to the ends of which the effects of even the recent notable advance did not extend. In still other cases, the ends of the bulbs have become almost or even completely separated from the main glacier by wastage of clear ice areas back of the terminus. The piedmont bulb develops during a period of advance; it may linger, in more or less mutilated condition, through a period of stagnation, receiving redevelopment when next an advance of sufficient volume occurs. In other words, it does not necessarily represent an existing state of activity and supply; for, because of the protection of a blanket of ablation moraine, it may long retain its position even in the face of warmth, abundant rainfall and failure of ice supply.

*Marginal and Terminal Deposits.*—Since on the seaward side of the coastal mountains, the ends of so many large glaciers lie in a temperate, rainy climate, the phenomena of terminal and marginal deposits are illustrated with great clearness, throwing much light on the origin of similar phenomena in the deposits of former continental glaciers. Particularly is this true of the piedmont areas, not only because of the wide extent of their margins, but also because they are existing examples of a type of glacier that was formerly common in the mountain regions of both Europe and America. It cannot be made a part of this address to consider this subject in detail, interesting and important though it is.[11] Suffice it to say, that in Alaska one may see in process of development both lateral and terminal moraines in great variety of form and composition, from stratified gravel or sand,

[11] See, Tarr, R. S., Some Phenomena of the Glacier Margins in the Yakutat Bay Region, Alaska, Zeitschr. für Gletscherkunde, vol. 3, 1908, pp. 81-110.

or clay, to true till; eskers and kames; outwash gravel plains and kettles of various forms and sizes; lacustrine deposits of many kinds and marginal lakes of various origins; marginal channels due to erosion and the work of marginal streams in deposit; indeed almost the whole series of phenomena which were present along the receding margin of the Pleistocene glaciers. There are phenomena of recession, of advance, and of alternate recession and advance in the course of which soil beds and plant remains are incorporated between distinct sheets of glacial deposits.

Of all the deposits at present being made in association with Alaskan glaciers, those made by the glacial streams are by far the most prominent. During the summer, torrents of water issue from the margins of the glaciers, and, where the ice is stagnant or thin enough for the existence of subglacial tunnels, from the central portions also. These torrents, doubtless esker-building beneath the glacier, spread out over alluvial fans, or broad outwash gravel plains, or long, narrow valley trains, which they are upbuilding by the extensive deposition that is made necessary by the overburdened condition of the streams on their escape from the ice tunnels. Over such a deposit the streams spread in a multitude of anastomosing branches, ever shifting in position as they aggrade their beds in the effort to establish a grade sufficient for the transportation of the sediment load. Within a few miles of the glacier front the slope of the aggrading streams may average 50 or 60 feet to the mile, and close by the glacier even much more than this.

So great is the velocity of the glacial torrents that good-sized stones are dragged along, and one can hear them striking together as they roll on down stream. First the boulders are dropped, then the gravel, then the sand, and with the change in material deposited is an associated change in grade; but throughout their course the grade of the glacial streams is commonly very steep for they are normally so charged with sediment, and much of the sediment is so coarse, that it quickly settles in a slow current. Schrader says that in its upper course the Klutena River has a grade of sixty feet a mile, then for twenty-eight miles an average grade of twenty-two feet a mile and a velocity of fourteen miles an hour. The Copper River, into which it empties, flows with a velocity of eight miles an hour.

*The Sediment Supply of the Glacial Streams.*—In volume, slope, and sediment load the Alaskan glacier streams are noteworthy. During a period of a few months each year, the drainage of a wide area, locked up in the form of snow and ice, is turned into torrents of running water which issue as full-fledged streams, and even as veritable rivers from near the glacier ends. A glacier that is just at the balance between supply and melting furnishes to the streams only that water which is brought down to or near to the ice front; but

in a glacier that is receding, there is added to this supply all that which is melted from the ice that is no longer moving forward. Therefore, where, as is so often the case in Alaska, the glaciers are stagnant or receding, the supply of water exceeds the normal.

The impressive volume of sediment, fine and coarse, which the glacial streams are transporting leads the inquiring mind to raise the question as to its origin. Streams having their source in the rainfall are not often so sediment-laden as the glacial streams normally are; indeed, even the exceptional land supplied streams are rarely as heavily burdened, even for a few days, as the glacial torrents normally are for several months. Particularly is the question of the origin of the finer grained sediment of interest. It is abnormal in quantity as compared with mountain streams in general, and yet it comes from a drainage area largely protected by snow and ice against those atmospheric agencies which transform hard rock to fine clay. Can there be any doubt but that the glacier which protects the rock against the atmospheric agencies must attack it with equal or even greater vigor, in order to obtain this vast burden of sediment that the streams bear away?[12]

*The Recession of Glaciers in Alaska.*—Throughout the world the general state of the glaciers is one of recession, with local exceptions, and it is as true of Alaska as of other regions. In the two regions where we have the longest record and the most detailed studies—Glacier Bay and Yakutat Bay—there have been great recessions during the period of observation, the continuation of a still greater earlier recession during the last century or so. For instance, in Yakutat Bay the tidal Nunatak Glacier receded at the rate of over 1,000 feet a year between 1899 and 1906, with a total recession of over a mile; and the nearby Hidden Glacier, ending on the land, receded at about a quarter of this rate. Prior to this observed recession, both Hidden and Nunatak glaciers had been so far advanced that they united and their combined front reached about twenty miles farther out than the present end of Nunatak Glacier, and ten miles beyond the present terminus of Hidden Glacier. From this advanced position there has been rapid and long continued recession which was in progress up to 1906 in Hidden Glacier and up to 1909 in Nunatak Glacier. If the observed rate of recent recession of Nunatak Glacier has been steadily maintained throughout the period, it is to be reckoned as of about a century duration.

In Glacier Bay the phenomena have been closely like those of Yakutat Bay. A long continued recession had been in progress when the Muir Glacier was studied by Wright in 1886, and by Reid in 1891 and 1892. At that time Muir Glacier front was about twenty

[12] See, Von Engeln, O. D. Zeitschr. für Gletscherkunde, vol. 6, 1911, pp. 138-144.

miles further inland than it had been one hundred or one hundred and fifty years before, and Grand Pacific Glacier front was about twice that distance back of the former terminus. Where ice had formerly filled the mountain valley to a depth of 3,000 feet, the fiord waters extended in 1892. This recession has continued since then, being especially noteworthy since 1899; and now (1911) both the Grand Pacific and the Muir Glacier fronts are nine or ten miles farther back than in 1892, the average recession being at a rate of not far from 2,500 feet a year for the nineteen years; but it is to be noted that the rate has not been regular, and that the greater part of the recession has occurred since 1899. The retreat has continued up to 1911 in all the glaciers of Glacier Bay with the single exception of Rendu Glacier (and a small cascading glacier near it), which has recently advanced about a mile and a half. Glacier Bay has been enlarged no less than fifty square miles by ice recession in a period of nineteen years. Assuming an average thickness of 750 to 1,000 feet, the total loss of ice in this period is not less than six or eight cubic miles. But to this must be added that which has been lost by ablation from above the present ice surface; and this is also an enormous amount, for all the lower glacier surfaces, even far back from their fronts, are now much lower than they were in 1892.

While these instances are the most striking of which there are records in Alaska, in our own studies Professor Martin and I have observed scores of other cases, widely separated, where there has been notable recent recession and where it is still in progress; and many instances have been made known to us by the observations of other workers. Therefore, the commonly accepted conclusion that recession is the general rule among the Alaskan glaciers seems warranted; yet the rule is by no means invariable. For example, Columbia Glacier began advancing in 1908, and Professor Martin found it still advancing in 1910, while in the same year he observed commencement of advance of several glaciers of different sizes in Prince William Sound and Copper River valley. We know also of recent advance of other Alaskan glaciers, the total known to us to have advanced since 1899, being forty-three, nine of which are in Yakutat Bay; but some of these forty-three advances are exceedingly slight; and forty-three glaciers form but a minute proportion of the whole number of Alaskan glaciers. These facts demonstrate that it cannot be assumed either that the recession is universal, or that it is not liable to interruption. Too little is known about Alaskan glacier history and about Alaskan climate and its variations, to warrant any generalization with regard to the possible future of its glaciers; it is not even certain that the present state of general recession is anything more than an episode.

*Advance of Glaciers as a Result of Earthquake Shaking.*—Of all the recent glacier advances of which we have record in Alaska, by far the most interesting are those of Yakutat Bay. Following the vigorous earthquakes of September 1899, and as I have elsewhere endeavored to show,[13] as an indirect result of them, has come a series of forward movements and transformations of a very spectacular character, interrupting a period of general recession and affecting even stagnant glaciers and piedmont bulbs. First there came a spasmodic advance of at least two small glaciers, and probably others that we failed to detect on our first expedition in 1905; then, in the interval between September 1905 and June 1906, an advance occurred in four larger glaciers; in 1906 or 1907 the Hidden Glacier advanced; in 1909 the still larger Lucia Glacier, and in 1909-1910 the Nunatak Glacier advanced. The progressive appearance of the advance, correlated with the length of the glaciers, has been set forth in the following table prepared by Professor Martin:

| NAME OF GLACIER | DATE OF ADVANCE | APPROXIMATE LENGTH OF GLACIER |
|---|---|---|
| Galiano | After 1895 and before 1905 | 2 or 3 miles |
| Unnamed Glacier | 1901 | 3 or 4 miles |
| Haenke | 1905–6 | 6 or 7 miles |
| Atrevida | 1905–6 | 8 miles |
| Variegated | 1905–6 | 10 miles |
| Marvine | 1905–6 | 10 miles (exclusive of portion in Malaspina piedmont area) |
| Hidden | 1906 or 1907 | 16 or 17 miles |
| Lucia | 1909 | 17 or 18 miles |
| Nunatak | 1910 | 20 miles |

[13] I have stated this theory in various publications, and in these have given a full statement of the facts and a discussion of their bearing on the theory, so that, in view of the general character of this address and its necessary briefness, only a very short and general statement is attempted. See especially Tarr, R. S., Second Expedition to Yakutat Bay, Alaska, Bull. Geog. Soc. Philadelphia, vol. 5, 1907, pp. 1-14; Recent Advance of Glaciers in the Yakutat Bay Region, Alaska, Bull. Geol. Soc. America, vol. 18, 1907, pp. 257-286; The Yakutat Bay Region, Alaska, Professional Paper No. 64, U. S. Geol. Survey, 1909; The Theory of Advance of Glaciers in Response to Earthquake Shaking, Zeitschrift für Gletscherkunde, vol. 5, 1910, pp. 1-35; also Tarr, R. S., and Martin, Lawrence, Recent Changes of Level in the Yakutat Bay Region, Alaska, Bull. Geol. Soc. America, vol. 17, 1906, pp. 29-64; The Yakutat Bay Earthquakes of September 1899, Professional Paper No. 69, U. S. Geol. Survey, 1912.

The advance involved a profound breaking of the glacier surface even where previously smooth and uncrevassed; the lower portion of the glacier was greatly thickened; where unconfined betwen mountain walls there was a notable spreading at the margins; and the free ends of the glaciers were bodily moved forward. In all cases the transformation was rapid and even spasmodic, requiring a period of but a few months for the complete cycle; and in all cases the advance was quickly followed by relapse into the previous state. In other words, a wave spread down through the glaciers with accompanying thickening, spreading, advance, and breaking of the rigid upper ice; but after its passage the glacier was left in essentially the same state of activity as before, even though that state had been complete stagnation in parts of the affected area.

In some cases the wave spent its effects in breaking, thickening and spreading a piedmont bulb, with little actual advance; in others, the effects of the thrust being confined by bordering mountain walls, and thereby concentrated on the frontal end, there was notable advance of the terminus. Such an advance is best illustrated in the Hidden Glacier whose front was pushed forward about two miles; and where the ice front stood in 1906 the glacier was 1,100 feet thick after the advance. During a brief, spasmodic advance, at least a third of a cubic mile of ice moved beyond the 1906 front; and great volumes of ice were also added to the glacier back of the old front, for in 1909 the glacier surface rose to a far greater height than in 1905 and 1906.

The theory put forward to account for this series of glacier advances is that the vigorous earthquakes of September, 1899, shook down such great avalanches of snow, ice and rock in the glacier reservoirs as to necessitate a wave of advance that swept down through the glaciers, reaching the terminus of the smaller ice tongues very quickly, and the larger ones at later dates, while up to the period of our last observations, in 1910, the very largest glaciers had not yet responded. Since the cause was a sudden and concentrated addition of large supplies to the glacier reservoirs, the resulting wave was naturally rapid in its passage, and it quickly subsided, while its effects in passing were both spasmodic and extreme.

A study of four seasons discovers only evidence favoring this theory, and since it is an efficient cause, known to have been actually present, while no facts are known to oppose it and a great number favor it, I feel convinced that the earthquake avalanche theory merits the wide acceptance that it has received. It adds a new, and, in favorable regions, probably a very important cause for fluctuations in glacier margins. How widely it may be extended in explanation of other glacier advances remains to be established by future studies; it is not to be expected that it will replace the theory of climatic

cause for glacier fluctuations; but it may well be expected to supplement it and perhaps in part replace it in regions of frequent earthquakes.

*Local Nature of Recent Great Advances.*—It is too early to attempt to explain all the known variations in Alaskan glaciers, for as yet the body of fact is limited both as to time and as to area. Yet there are some significant features that are well worth consideration. Attention has already been directed to the fact that there has been a very great recent recession of the ice fronts in Glacier Bay and a similar recession in the Yakutat Bay region one hundred and fifty miles to the northwest. This recession, which has been in progress for the past century or more, is really but part of a cycle, in which the glaciers are still receding toward a former minimum. Having at an earlier period been far advanced, and having held this position for a long time, the glaciers in both regions receded to a stand even farther back than the present ice fronts, and remained there long enough to permit the growth of mature forests; then came an advance pushing the ice fronts forward from twenty to fifty miles. This advance is known to have been of brief duration, for the gravels over which the glaciers advanced were not removed by the ice erosion; and it was quickly succeeded by the rapid recession that has been in progress during most of the period of observation.

So great an advance, followed by so great a recession, might be expected to be part of a general cycle affecting all or a large part of the Alaskan field. Yet such is not the case, for in Prince William Sound, two hundred and fifty to three hundred miles to the west of Yakutat Bay the recent glacier history has been wholly different. In no case have the glaciers recently had a position far beyond their present fronts, while in some cases it is certain that they are to-day as far out as they have been in a century or two. This is especially clearly seen to be the case in Columbia Glacier, which in 1909 and 1910 was advancing into and destroying a mature forest. Forest also grows on the mountain slopes above the glacier for many miles back from its front, suggesting that this glacier is now in a state of unusual advance analogous to that experienced a century or more ago by glaciers to the southeast. Since there is no reason to suspect that a general cause which was operating to bring about glacier advance in the Alaskan coastal region could suffer retardation of a full century in the Prince William Sound region, we are forced to the alternate view that even such great advances and recessions as those proved for the Yakutat and Glacier Bay regions, are localized phenomena. Whether due to uplift or depression, to vigorous and repeated earthquake shakings, or to local climatic variations remains yet to be determined.

*Cause of the Recent Retreat of Muir Glacier.*—It has been a generally favorite theory that the remarkable recession of Muir Glacier since 1899 is an indirect result of the great earthquakes of September, 1899. Latterly it has been proposed that the recession is due not to this cause but to the enlargement of ice area exposed to the sea water and consequently to wastage by iceberg discharge. Neither of these theories, nor the two combined, are either competent or needed to explain the phenomena of recession, though doubtless each has been a factor in it. Granting the maximum disturbance by earthquake shaking, and granting even that the glacier could be broken from surface to bottom, which is highly improbable in view of the nature of ice under pressure, the cracks would certainly heal and the ice become cemented in its lower portions soon after the breaking. There would be no basis for the continuation of the effect of the earthquakes for a number of years after the shocks themselves had died out; yet recession has continued for twelve years after the earthquakes. Moreover, recession began many years before the earthquakes, though the rate has been much increased since 1899. As to the theory that the recession is due to the enlarged area of ice exposed to salt water, that is surely an efficient aid in recession; but it does not account for the continuation of notable recession of other glaciers of the region which now have less, rather than greater, area exposed to the salt water. Nor does it account for the excessive wastage along land margins and on ice surfaces back from the fronts. In view of the fact that the glaciers of Yakutat and Glacier Bays have been in a state of rapid recession for a century or two, all that is necessary in explanation of the recession since 1899, is to consider it an accelerated part of this grand retreat which must be due to a deficiency of snow supply following an excess in supply, or an emptying of the glacier reservoirs succeeding a filling of them. Of course, the rate of recession may readily have been temporarily modified by crevassing due to earthquake shaking, or locally modified by variation in exposure to wastage, or checked or increased by variations in precipitation or temperature. These, or any other temporary or local causes, are but minor episodes in the general withdrawal of glaciers which a century or two ago had for some reason, as yet unknown, been made to advance farther than they could remain.

*Some of the Factors Involved in the Phenomena of Advance and Retreat.*—Under the simplest of circumstances the advance or retreat of a series of glaciers is a complex phenomenon in which so many factors are involved that a full analysis of them cannot be undertaken here. Yet some of the factors stand out with such distinctness that I may take time briefly to point them out. The nature of the glacier terminus is of fundamental importance. If the end of an ice tongue is in

water it makes a great difference in the rate both of advance and recession whether the water is salt or fresh, whether it is deep or shallow, whether it is in active movement or is quiet, whether there is or is not a free escape for the icebergs, and whether the relative area of ice cliff is small or great. All these factors are effective in addition to the rate of supply of ice to be discharged. If, on the other hand, the terminus is on the land, there are questions of exposure, of elevation, and of amount of moraine cover, as well as the amount of ice supplied.

*Illustration from Yakutat Bay.*—It is clear that there must be a very great difference, especially in recession, according to whether the ice front is on the land or in the sea, for in the latter position wastage is far more rapid than in the former. This finds clear illustration in the Yakutat Bay region, for during the recent great expansion of the glaciers a century or two ago, not only were the tidal Nunatak, Turner and Hubbard glaciers caused to advance but the glaciers ending on the land also pushed forward, presumably at about the same time. Along the margin of Malaspina Glacier, for instance, the same phenomena of overridden gravels and buried forests are discovered as in the area over which Nunatak-Hidden glacier advanced. But while the tidal glaciers have receded ten to twenty miles, the recession of Malaspina Glacier has been, at the most, but a fraction of a mile; and in some parts of its moraine-covered margin, on which forest grows, it has remained practically stationary for at least half a century. This extreme difference may possibly be in part due to a more constant maintenance of the ice supply in the Malaspina Glacier, though of this there is no proof; it certainly is partly due to the difference in rate of recession of glaciers terminating on the land and in the sea.

*Modification of Local Climate as a Result of Advance and Retreat.*—In interpreting both the cause and the rate of advance or recession of glaciers it is evident that the mere fact of advance encourages advance, while recession encourages continuation of recession. When a glacier advances, the area of ice surface is increased, and its level rises, while with retreat the glacier surface is lowered and the area of ice is decreased; and if the terminus is in the sea, there is a variation in the amount of floating ice with advance or recession. These changes produce a very pronounced effect on local climate, influencing both snowfall and ablation. Though the extent of the influence is naturally variable, it is roughly proportionate to the amount of the advance or retreat and to the area and height to which the variation extends. Other things being equal, the influence of an advance in encouraging advance is greater and more prolonged when the ice ends on the land than when its terminus is in the sea; for on the land the ice spreads farther and remains in position longer. Thus the climatic influence

of the last advance of Malaspina Glacier is still dominant, while that of the neighboring Hubbard Glacier has been very greatly reduced by its notable recession.

In illustration of these principles it may be stated that photographs of Hidden Glacier, which in the interval between 1905 and 1909, had advanced two miles and had become greatly thickened, show a very notable difference in the amount of snow on and above the ice. This is undoubtedly due to the double cause of greater snowfall and decreased melting, brought about by a modification of the local climate as a result of the advance. At Muir Glacier, which in the interval between 1892 and 1911, has suffered such excessive recession and lowering of its surface, the climatic difference is also distinctly noticeable in photographs, but with results of exactly the opposite kind. Here there is a smaller area of ice, the surface of that which remains is much lower than formerly, a larger proportion of the surface is covered with moraine or discolored by debris, and the snow-covered area on the mountain slopes is greatly diminished. Without doubt the depth of annual snowfall is markedly decreased, while the amount of ablation is notably increased in 1911, as compared with 1892. Thus when a deficiency of snowfall gives rise to a recession, the rate of ablation may come to be considerably in excess of the amount by which the ice supply is deficient, and the rate of retreat therefore may become much more rapid than would be expected from the mere difference in ice supply.

*Recession Following Advance.*—The problem of advance and recession is still further complicated by the apparent manner in which glacier advances take place. As shown by Finsterwalder and others,[14] the Vernagt Glacier of the Tyrol responds to climatic variations by the passage through the glacier of a wave which causes the terminus to move forward, the forward movement being concentrated in a brief period of time. Other glaciers, in the Himalayas, in Patagonia, and in Spitzbergen, whose ends have been rapidly and notably pushed forward are apparently illustrations of the same principle; and because of the peculiar nature of the cause for the wave, the Yakutat Bay glaciers furnish illustrations of an even more spasmodic move-

[14] Finsterwalder, S., Der Vernagtferner, Wissenschaftliche Erganzungshefte zur Zeitschrift des D. u. O. Alpenvereins, 1. Band, 1. Heft. Graz, 1897. Anhang. Blumcke, A. und Hess H., Die Hachmessungen am Vernagtferner; Blumcke, A. und Hess, H., Beobachtungen an den Gletschern des Rofentales, Mitt. des D. u. O. A. -V., Jahrgang 1900, Nr. 4; Einiges uber den Vernagtferner, ibid. Jahrgang 1902, Nr. 18; Tiefbohrungen auf dem Hintereisferner, 1902, ibid. Jahrgang 1902, Nr. 21; Tiefbohrungen am Hintereisferner im Sommer 1908, Zeitschrift für Gletscherkunde, Band III, 1909, pp. 232-236; Tiefbohrungen am Hintereisgletscher, 1909, Ibid. Band IV, 1909, pp. 66-70; Hess, H., Zur Mechanik der Gletschervorstosse, Petermanns Geogr. Mitt., 1902, Heft V; Hess, H., Probleme der Gletscherkunde, Zeitschrift für Gletscherkunde, Band I, 1906, pp. 241-254.

ment, and a more rapid subsidence of the wave of advance. There are many instances of minor, or minute, advances of glacier fronts; and we also know of a number of cases of noteworthy advances in Alaska and elsewhere. The latter all seem to be illustrations of the same principle,—that a wave of advance, concentrated on the terminus of the glacier, pushes it far forward; then follows a relative deficiency of supply and consequent retreat. In the recently advanced glaciers of the Yakutat Bay region the subsequent deficiency has been so great that stagnation has immediately followed advance.

We have not yet a body of fact large enough to warrant the statement of a law, but such knowledge as we possess indicates that there is reason to expect relatively rapid recession following an advance because a deficiency of supply follows as a necessary result of the utilization of a part of the ice supply in the progress of the wave of advance. In other words the reservoir is temporarily depleted by the drain upon it during the advance.

Former Glaciation.—The major part of this address has been devoted to the existing glaciers and their recent history, for this has been the field of my most extensive study. But little time remains for a consideration of the former glaciation, and what is said must of necessity be brief, and deal with only the most general and fundamental points.

*Extent of Former Glaciers.*—It is now a well known fact that in recent geologic time there has been a very notable expansion of Alaskan glaciers both along the coast and in the interior. The fiords of southeastern Alaska were filled with ice to their seaward entrances, and the same was true as far west as Alaska Peninsula. Thus there was a vastly greater ice-covered area on the seaward side of the coastal mountains than now exists there. In the interior there was also notable expansion on the inner side of the coastal mountains, on both sides of the Wrangell and Alaska Ranges, and in the Endicott Mountains. Elsewhere in the mountains of the interior, even where there are now no living glaciers, there were valley tongues, and perhaps even expanded piedmont bulbs. All this glaciation was, however, purely of the mountain type, and far the greater part of Alaska was untouched by it.

Along the coast there were extensive piedmont glaciers, and there were vast piedmont ice sheets filling the fiords to a depth of several thousand feet, overflowing the low islands and peninsulas now separating them, and discharging icebergs into the ocean. Piedmont glaciers also developed along the inner face of the coastal mountains and on both sides of the Wrangell Mountains, and the Alaska Range.

By far the greatest area of ice in the interior was that which, in its maximum stage, nearly or quite filled the great basin that lies between

the coastal mountains, the Wrangell Mountains and the Alaska Range, forming a great *intermont* glacier by the junction of a series of piedmont glaciers. The exact extent and the characteristics of this glacier are not yet determined; and it is not certain that it filled the entire Copper River Basin, though it probably did, and even extended into the Susitna Valley.

*Deposits of Former Glaciers.*—The deposits of this former glaciation are not usually extensive among the mountains, whence they have easily been removed by subsequent denudation; nor are they very notable in most places along the coast, for there the greater portion of the deposits doubtless lies beneath the sea. Only in a few places, as in the foreland that skirts the seaward base of the Fairweather Range, is there an extensive area of deposit; elsewhere the general scarcity of glacial deposit is usually striking.

In the interior, on the other hand, and notably in the Copper River Basin, there is a remarkable development of glacial and glacio-fluviatile deposit formed during the period of glaciation and during its stages of advance and of recession, of which the present must be considered a part. Here one finds the greater number of glacial features common to an area of continental glaciation,—lake and glacial stream deposits, loess, till, eskers, kames, moraines and marginal channels are found in perfect development over a wide area. One familiar with glacial deposits in Europe or America finds himself quite at home in the Copper River Basin.

*The Period of Expansion.*—There has not been enough study of the glacial deposits to render it possible to state whether the history of the glaciation in Alaska presents the same complexity as that observed in Europe and eastern America; nor can it even be assumed that the Alaskan glaciation was contemporaneous with the glaciation of these lands. Yet, although very extensive glaciers still exist in Alaska, and although these are certainly the descendants of the former expanded glaciers, it is entirely possible that the time since the maximum expansion is as great as that in other northern lands, such as Norway and Scotland. I can see no noticeable difference either in the extent of post-glacial denudation, or in the weathering of glacial deposits in Alaska and the Alps, or Norway, or Scotland. The greatest expansion of Alaskan glaciers certainly occurred many centuries ago, and may well have been as long ago as the time when the glaciers of the Alps shrank back into the mountain valleys. The vast work performed by glacial erosion in the Alaskan fiords clearly proves that the period of expansion of glaciers was of long duration.

*Difference in Extent of Recession.*—There is one very puzzling condition that renders the solution of the problem of the time of maximum expansion difficult to solve. In southeastern Alaska and in Prince William Sound the tidal glacier fronts now lie from 75 to

100 miles farther back than they were in the period of greatest expansion, and vast areas of land and water have been uncovered by the recession of the glaciers. So also there has been a very large area uncovered by glacier recession in interior Alaska. But in the coastal area between Cross Sound and Prince William Sound, the glaciers of to-day are only slightly less extensive than they were at the maximum. According to G. C. Martin,[15] the present surface of Martin River Glacier is only 600 or 700 feet lower than during the maximum glaciation, while Bering Glacier is only about 200 feet lower; and the horizontal extension of the glaciers at the period of maximum expansion was only very slightly beyond the present borders. Malaspina Glacier has shrunk more than the Bering, but even this is far nearer the maximum than the glaciers of Prince William Sound toward the west, or those of the Inside Passage to the southeast, or those of the interior to the north. In the same region with Malaspina Glacier, the expansion of the Nunatak-Hidden Glacier, of a century or two ago, extended to within ten or fifteen miles of the earlier maximum.

From these facts it is evident that locally, near the center of the coastal area of Alaskan glaciation, the present day glaciers are only a little short of their former maximum. This may be due to recent extensive uplift of the mountains in which these glaciers have their source, or to other local causes; or the entire history of Alaskan glaciation may be related to changes in elevation, and wholly unrelated to those causes that gave rise to the development of continental glaciation in Europe and eastern North America. We are not now in possession of a sufficient body of fact to warrant further discussion of this problem.

Conclusion.—This brief analysis makes it clear that up to the present time only a beginning has been made in the research in the field of Alaskan glaciers and glaciation. Enough has been done, however, to show the existence of interesting and important problems, to permit a few of them to be set forth in concrete form, and to discover facts that have a bearing upon some of them. But there is so much yet to be learned, so many more facts are needed, there is so wide a field that is wholly unknown, and the period of observation is so limited that anyone who undertakes to consider the general problems of this broad and complicated field cannot but feel appalled at the limitations surrounding his attempt. At best, with all the help that he can obtain from the work of others, he can only hope to make a step toward the understanding of the conditions and problems of this great field. I do not delude myself with the belief that in this address I have done more than this.

[15] Martin, G. C., Geology and Mineral Resources of the Controller Bay Region, Alaska, Bull. No. 375, U. S. Geol. Survey, 1908, pp. 50-52.

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# AN EFFORT TO CONTROL A GLACIAL STREAM*

RALPH S. TARR AND LAWRENCE MARTIN

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GLACIERS AND TRANSPORTATION ROUTES IN ALASKA.—Throughout the coast region of Alaska there are many relationships between glaciers and man's attempt to establish transportation routes. The junior author has previously discussed before the Association of American Geographers some of the glacier highways in Alaska,[1] and

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The authors shared equally in the field work upon which this paper is based. The lamented death of the senior author on March 21, 1912, occurred before the paper was written in the form here presented. The junior author assumes full responsibility for any errors of interpretation.

[1] Martin, Lawrence, Glacial Highways in Alaska, Chicago meeting, December, 1907, Annals, Assoc. Amer. Geographers, Vol. I, 1911, p. 109; Mastering the Alaskan Glacier Barriers, Scientific American Supplement, Vol. LXXI, 1911, pp. 305-307; Crossing the Alaskan Glaciers, Colliers Weekly, Vol. XLVII, July 15, 1911, p. 20; The National Geographic Society Researches in Alaska, Nat. Geog. Mag., Vol. XXII, 1911, pp. 541-548.

both authors have previously described the complications of glaciers and railway building along the Copper River and Northwestern Railway.[2]

The combination of (a) lofty mountains along the Pacific coast, (b) heavy precipitation including much snowfall, resulting in large ice tongues which completely fill or project into the passes across the coast range, and (c) geographical distribution of harbors in relation to resources of the region inside the coast ranges, has resulted in the necessity of (1) using the glaciers as temporary highways, as at Valdez Glacier and several other ice tongues, or (2) following valleys partly barred by ice tongues, as along the Copper River and Northwestern Railway, or (3) building railways and roads over snowy passes, as on the White Pass and Yukon Railway and several other routes to the interior.

The case described in this paper is of a different sort. The transportation route in question does not cross a glacier, but it goes so close to one that the glacial streams cause decided complications. Railway engineers have not previously had to deal with this sort of stream, and the locating engineer so thoroughly misunderstood the habit and power of glacial streams that his successor has had a grave problem to deal with. He was at work upon this problem at the time of the visit of the authors to the Alaska Northern Railway in 1911, in connection with the third glacial research expedition of the National Geographic Society.

The Alaska Northern Railway.—The Alaska Northern, originally called the Alaska Central Railway, extends from the town of Seward, on the Kenai Peninsula just west of Prince William Sound, toward the Matanuska coal field. Only seventy-two miles of this railway were built up to 1911 but it will doubtless soon be constructed the remaining seventy-eight miles to this coal field. This railway may eventually be extended to the Tanana and Yukon valleys in the interior of Alaska, especially if it is purchased by the government, as was recently recommended by the Secretary of the Interior.

The Alaska Northern Railway, as it was built, crosses two passes, the highest of which is about 1,080 feet above sea level. Each of these passes was considerably lowered by glacial erosion. In descending the northern side of the higher of these passes it has been necessary to construct several great curves and loops including one spectacular, high spiral trestle, close to the large, inactive Bartlett Glacier. A little farther north the railway line descends out of a hanging

[2] Tarr, R. S. and Martin, Lawrence, Geographical Aspects of Alaskan Glaciation, Cambridge meeting, December, 1909, Annals, Assoc. Amer. Geographers, Vol. I, 1911, p. 121; The National Geographic Society's Alaskan Expedition of 1909, Nat. Geog. Mag., Vol. XXI, 1910, pp. 1-54.

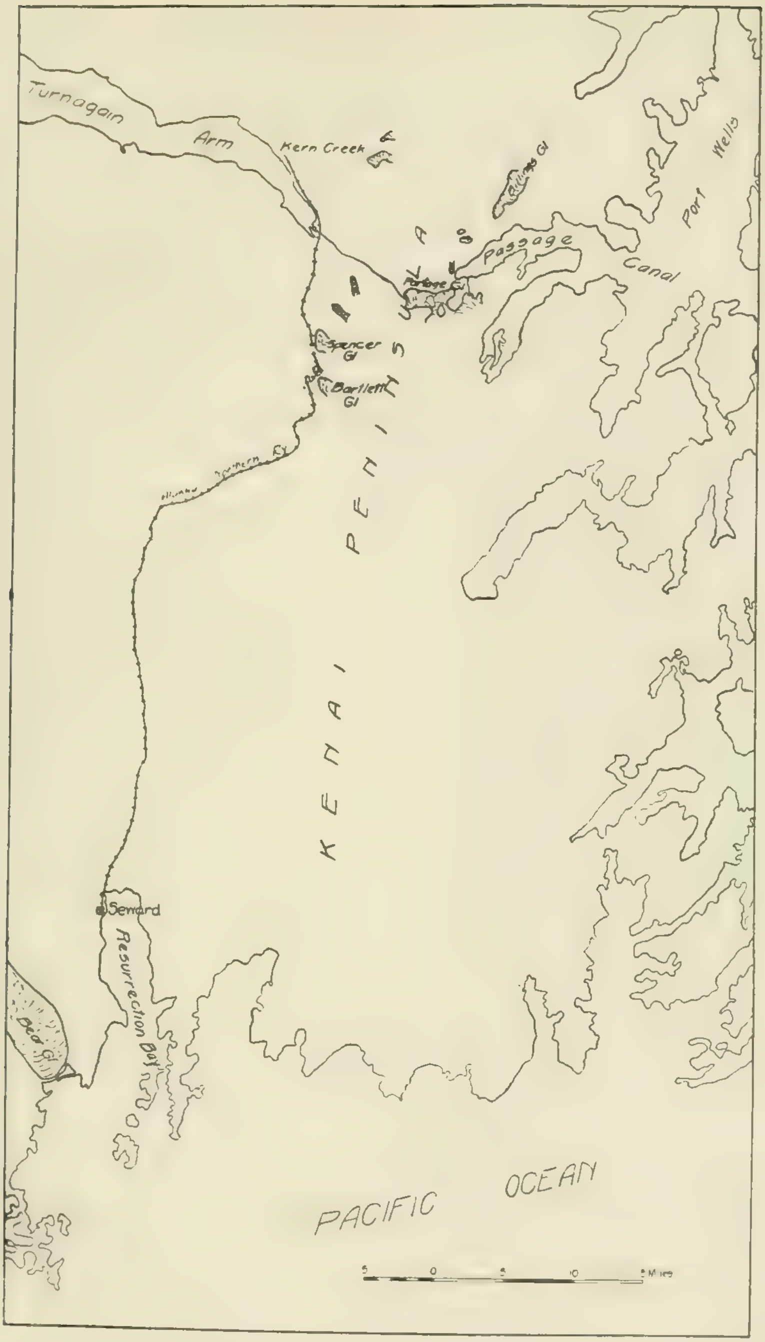


FIG. 1.—Map showing Alaska Northern Railway and its relationship to the Turnagain Arm of Cook Inlet and the Passage Canal fiord in western Prince William Sound.

valley into the main valley occupied by Spencer Glacier. The lip of the hanging valley is gashed by a deep, post-glacial gorge. The railway follows the side of the gorge, whose sides are so steep that six short, curving tunnels have been dug. Below the northernmost of these tunnels the railway reaches the level of the main valley and passes close to the front of Spencer Glacier (Fig. 3).

THE SPENCER GLACIER.—The Spencer Glacier flows northwestward from unexplored snowfields in the Kenai Peninsula, terminating seven miles south of the Turnagain Arm of Cook Inlet. It is nearly a mile and a half wide at the terminus. The glacier is clean, is only moderately crevassed (Plate II, a) and is flowing forward so slowly that the ice at the terminus was melted back thirty-six feet between 1905 and 1911. Four large streams emerge from the glacier, three of them on the western and one on the northern margin. The latter, which is the only one of especial interest in this paper, flows into a box canyon a few hundred feet from the point of emergence, continuing in this rock gorge for over a mile.

THE TERMINAL MORAINE.—A terminal moraine was built by Spencer Glacier at a period of recent expansion. Part of this moraine has been destroyed by the glacial streams, and the remaining portion is over a mile in length and an eighth to a sixteenth of a mile wide. It rises to a height of twenty to twenty-five feet and is made up chiefly of rounded stream gravels, evidently the material of an older outwash gravel plain pushed up by the glacier in its recent advance, when a little till was added. The eastern edge of this moraine has been cut up into half a dozen disconnected hillocks, separated by stream channels. The remainder of the terminal moraine is a solid, somewhat knobby mass, with marked lobes on the outer edge (Plate II, b). The glacier has retreated about one thousand feet from the outer edge of the terminal moraine, and a few youthful shrubs have taken root upon its surface.

THE OUTWASH GRAVEL FAN.—Extending northward from the terminal moraine of Spencer Glacier to the head of Turnagain Arm is a broad valley train of outwash gravels which fill this mountain valley from side to side. The outwash gravels also fill most of the area between the terminal moraine and the present edge of the glacier. Where the eastern portion of the terminal moraine has been cut away by the glacial streams an alluvial fan of steep slope extends northward (Plate II, b, and Plate III, a) and merges with the valley train. This alluvial fan is made up of rather coarse outwash gravel and slopes northward at the rate of seventy-three feet to the mile (Fig. 2). Close to the ice front the gravels have been laid down upon the outer edge of the glacier and the buried ice has melted, giving rise to a series of kettles. At the very margin of the glacier the ice has

recently shrunk away from the gravels; forming a long narrow fosse with one wall of ice and one of gravels underlain by ice.

THE BARREN ZONE.—The terminal moraine and adjacent outwash gravel plain are practically without vegetation and there is also a barren zone on either margin of the glacier (Plate II, a), where melting has caused it to shrink away from the valley slopes. This lateral barren zone is a surface of practically naked rock, forming a striking contrast with the higher slopes, which support a dense, mature forest of conifers, with a thick carpet of moss. The trees attain diameters of forty-six to fifty inches and are a century or more of age. In the barren zone the soil, the moss, and the trees have all been removed by a recent advance of Spencer Glacier. In some of the hollows a little gravel and till have been left during the retreat of the glacier margins. Scattered through this and lying upon the bare rock ledges are many logs and fragments of stumps of trees, together with quantities of finely-shredded wood. Here and there, in parts of the barren zone where soil is present, small alders and willows have sprung up since the zone was vacated by the ice. The oldest of these shrubs were twelve years of age in 1911.

RECENT EXPANSION OF SPENCER GLACIER.—The barren zone and the terminal moraine show that in comparatively recent times this ice tongue has had a period of expansion. During this expansion the glacier was larger than it had previously been for a century or more, for the mature forest was eroded away in what is now the barren zone. The youthful shrubs in the barren zone prove that this expansion was at least twelve years before 1911, or not later than 1898 or 1899. Our observations in similar barren zones of Alaskan glaciers show that such periods of expansion are short-lived and that vegetation springs up immediately, suggesting that the period of expansion was not over a year or two before 1898. There are no observations by visitors to Spencer Glacier to tell anything further as to the exact date of this latest period of glacial expansion.

ORIGINAL LOCATION OF ALASKA NORTHERN RAILWAY.—The portion of the railway near Spencer Glacier was surveyed some time before January 8, 1906 and the track was laid in August, 1907. The original location has three conspicuous defects. First it goes within the barren zone on the southwestern margin of the glacier, where the northernmost tunnel goes through a rock spur over which the glacier extended in its period of recent expansion (Fig. 3). This is on the side of the rock gorge by which the stream from the Bartlett Glacier near the pass descends from its hanging valley to the valley of Spencer Glacier. Between the two previous tunnels this stream is reinforced by a glacial stream which plunges over a beautiful waterfall to the gorge, the retreating edge of the glacier being only a few

hundred yards from the gorge in 1911. Between the two northernmost tunnels, however, the edge of the barren zone crosses the track, crossing it again directly above the roof of the last tunnel. At this locality a renewal of activity as slight as that just before 1898 would destroy this portion of the railway.

The second defect in original location is where the railway, after crossing the westernmost and largest of the streams of Spencer Glacier by a high trestle, continues northeastward by a long tangent which is built on the terminal moraine itself for over half a mile (Fig. 3) and then goes on across the northern alluvial fan of outwash gravels. To have located this railway upon the terminal moraine of a living glacier which has retreated less than a quarter mile from the moraine built by it not much over a dozen years ago, shows a lack of knowledge of glaciers and an unwarranted belief that continued recession is inevitable. Our own study of ice tongues, bringing out the facts that (a) sixty-nine glaciers in Alaska have advanced since 1786, forty-eight of them since 1899 and (b) that the terminus of one glacier has moved forward a mile in ten months, two others one and a half and two miles, respectively, in less than three years and probably in a single year, lead us to regard this railway location as extremely ill-advised.

The third poorly-considered feature of the railway location near Spencer Glacier was the building of the railway line across the northern alluvial fan of outwash gravels. Here the mile and a half of railway immediately northeast of the terminal moraine is located so close to the glacier that the streams from the retreating ice tongue have already done thousands of dollars worth of damage to the grade and the bridges. This would continue with inactivity and retreat of the ice and would be even worse if the glacier should advance, making itself felt long before the ice moved forward to the railway itself.

It should be said in justice to the railway engineers that these are errors of location which any engineer without experience with the habits of glacial streams might have made, in the belief that glaciers in Alaska are generally retreating. When built, the railway was elevated on piles above the surface of a good part of the alluvial fan and an adequate number of bridges and culverts, most of them with openings fourteen feet high in the center, was built to accommodate the existing streams. What was overlooked was (a) that the fan is still being built up, and (b) that the glacial streams, like all streams on alluvial fans, are shifting rapidly in their courses.

Disadvantages of Original Location.—The disadvantages in the original location of the portion of the Alaska Northern Railway near Spencer Glacier soon became apparent, especially in the railway grade upon the outwash fan (Plate IV). The anastomosing streams from the northern part of the glacier soon abandoned their channels

beneath the bridges and culverts and established new courses across the railway track. These streams flow with great velocity and carry much coarse sediment. They rapidly filled the elevated portions of the trestle so that a section of the track which was originally so high above the fan that a team of horses could be driven underneath soon had the gravels at the level of the track. Bridge openings which were two to nine feet high and thirty-six to two hundred and eight feet long were completely filled (Plate IV, a) in the three years before August, 1910.[3] The gravels were laid down in some places to a depth of six to fifteen feet above the level of the rails. Bridge No. 93 was filled to a depth of six feet, bridge No. 94 to a depth of five feet, and others to a depth of nine to fourteen feet. The twenty bridges and culverts in a distance of one and a half miles were all filled solid and abandoned and the streams flowed over or cut away the track in a score of new channels.

Unsuccessful Attempt to Divert the Glacial Stream.—The railway engineers at once took measures to divert the glacial stream from the northern margin of the glacier so that it should flow northwestward and cross the railway near the terminal moraine where the track was elevated some little distance above the gravels. It was thought that by throwing two dikes (Fig. 2) across the stream course this diversion would be possible.

Consequently a dam of piling twelve feet high, filled with coarse rubble, was built westward from the valley wall to an isolated rock hill one hundred and seventy feet distant. From this hill a dike twenty-one hundred feet long was built northwestward to a point north of the railway. This dike was made of a double line of heavy piling driven deeply into the gravels. The two lines of closely-set piles were tied together by heavy log cribwork. The twelve foot space between the piles was filled with large fragments of heavy, angular rocks. Small wing dams projected at an angle from the upstream face of the dike to keep the stream from undercutting the piles.

The short upper dam held, but was filled by the glacial stream to a height of ten to eleven feet. The long dike did divert the stream for a time but it was impossible permanently to turn from their courses glacial streams flowing down a slope of seventy-three feet to the mile and armed with coarse gravel for cutting-tools. The streams, therefore, soon broke through the dike not once but in half a dozen places, as is shown in Fig. 2, resuming their normal courses down the northeastern slope of the alluvial fan. The havoc which they wrought in the dike is shown in Plate III, b.

Since the failure of the dike, the railway has undergone a continual struggle with the stream. The building of new bridges, the

[3] This and the following figures were furnished us in the summer of 1911 by Col. A. W. Swanitz, chief engineer of the Alaskan Northern Railway.

shovelling of gravel from the track, the raising of the grade to accommodate the upbuilding of the fan, and the replacing of rails has been a continual source of trouble and expense, to say nothing of the interruptions of traffic on the railway. Several log cabins occupied by the workmen on the railway in 1907 were half buried in the stream gravels in 1911. The conditions along the railway when the authors visited Spencer Glacier in 1911 are suggested by Plates IV and V.

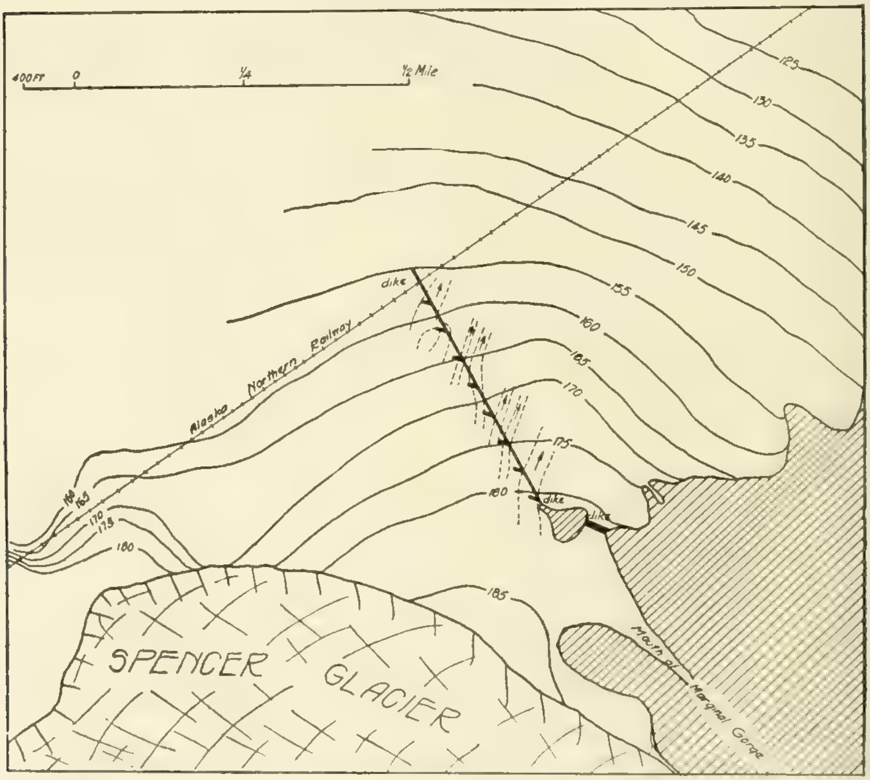


FIG. 2.—Contour map showing the northern alluvial fan of outwash gravels at Spencer Glacier, the dikes built to divert the glacial streams from the Alaska Northern Railway and places where streams broke through the dikes (after a map by the railway engineers).

In some places the heavy steel rails had been bent into sinuous curves, and when it is remembered that the stretch of track across the alluvial fan is a tangent or perfectly straight section of the railway the pictures speak for themselves. We wondered in some places whether we could safely take a handcar over some portions of the track, but, as the rails were bent in parallel curves, we afterwards rode over some of these snake-like curves, first in a heavy gasoline-propelled railway car, and later on a freight-train behind a standard locomotive. On June 25th when the junior author made the map reproduced here

as Fig. 3 one mile of track had thirteen dry bridges, filled flush with gravel and four or five streams were flowing beneath the track where there was no bridge, one stream having shifted half way from under its bridge (Plate V, b), and another flowing over the tops of the rails. These conditions called for prompt, efficient action; and the railway was then fortunate enough to have a chief engineer fully capable of coping with the situation.

The Plan for Controlling the Stream in 1911.—This engineer, Col. A. W. Swanitz, worked out in the summer of 1911 a new plan for controlling the glacial stream. Col. Swanitz, it should be said, was not connected with the railway at the time of the original location and the attempted diversion by the dikes. The authors are deeply indebted to Col. Swanitz and to the present President of the railway, Mr. O. G. Laberee, for entertainment at the engineer's camp on the terminal moraine of Spencer Glacier at the time this ingenious plan of glacial stream diversion was being carried out in June, 1911.

Col. Swanitz' plan was (1) to dam the stream at the point where it emerges from the glacier and plunges into the marginal gorge, (2) to divert it along the present glacier margin for two miles, and (3) to send it under the railway at a point in the terminal moraine (q. Fig. 3) where there is a high trestle.

Details of the Stream Adjustment.—*The Upper Dam.*—The marginal gorge near the outer edge of the barren zone lends itself to the stream diversion (Plate VI, b), for it is a box canyon about ninety feet deep and not over twelve or fifteen feet wide. The engineer and his men planned to blast down rock from the walls of this canyon by one great charge of dynamite and to form a dam which should hold in a small lake (a, Fig. 3). A rise of a few feet in the surface of this lake would allow the water to overflow along the glacier margin. A little work resulted in the clearing out of a channel to accommodate this new outlet. The dynamite was transported up to the head of the marginal gorge by sled on the glacier surface.

*The Marginal Channel.*—The new marginal channel (m-m, Fig. 3) was to be about a mile long and had one rock wall and one ice wall (Plates II, a, and X, a). A small stream emerged from the glacier margin near the lower end of the proposed new channel but there was no water flowing along the greater part of the edge of the glacier where the new stream was to go.

*The Lower Dam and Lake.*—A lower dam was built at the southwestern terminus of the new marginal channel. This (n, Fig. 3), connected the western end of the rocky hill of the barren zone with a hillock of gravels underlain by ice and crossed an abandoned stream channel which it was necessary to block. This dam was to hold in a

shallow lake whose new outlet was to be a short ice channel across the margin of the glacier to connect with a natural channel in the fosse to the west. This lower dam was constructed of angular rock. Col. Swanitz' ingenuity was displayed in the construction of this

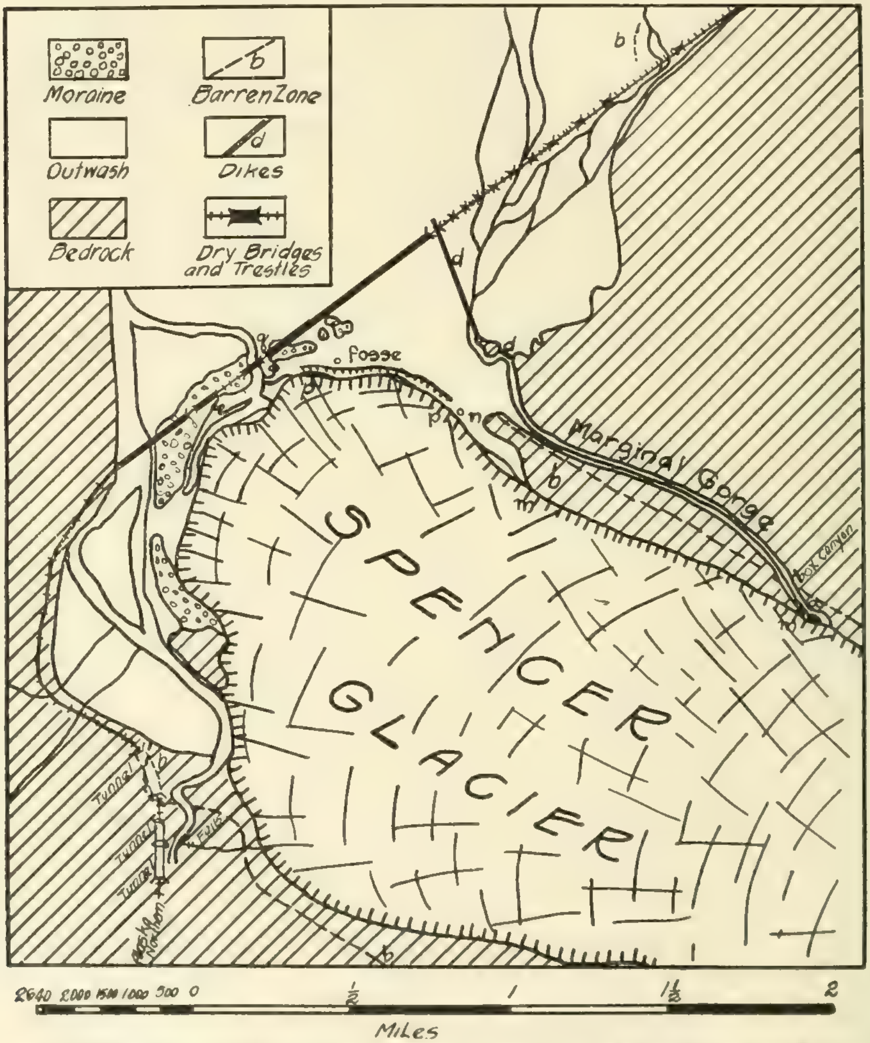


FIG. 3.—Sketch map of the Spencer Glacier, showing its relationship to the Alaska Northern Railway. Mapped June 25-26, 1911, by the junior author.

dam. He moved a heavy pile driver three quarters of a mile from the railway to a site at the glacier margin, letting the pile driver pull itself along on skids laid upon the gravels of the alluvial fan. This was done by burying a log some distance ahead of the driver and pulling the heavy apparatus up to the log by winding up a steel

cable on the drum of the pile driver. The pile driver dragged behind it a rude sled with a load of coal. The pile driver was set up at one end of the dam and its tower was connected by cable with the rock hill upon which a stone quarry had been opened in the rough, glacially-plucked granite surface of the barren zone. This cable carried the huge blocks of stone to the dam, where small spruce trees were laid in the interstices between the stones. By this method the lower dam was built in a few days.

*Dyeing a Glacial Stream.*—Another evidence of the ingenuity of the railway engineer was his method of tracing a glacial stream which disappeared beneath the ice just above the lower dam and which was thought to be identical with a geyser-like stream which boiled up a quarter mile to the southwest in the fosse.

Col. Swanitz purchased a quantity of red aniline dye which the junior author put in the stream where it disappeared beneath the glacier (Plate VIII, a), the senior author and Col. Swanitz watching for the red color at the geyser-like stream a quarter mile below (Plate VIII, b). They were not absolutely certain that the red water was recognized, as a barrel rather than a pail full of dye would be better for this sort of experiment in a rapidly-moving glacial stream. The identity of the stream was established later, however, by sending fragments of trees through the sub-glacial channel. So far as we know no one has previously attempted to trace a subglacial stream by this ingenious method.

*The Ice Channel.*—The shallow lake, held in by the lower dam had to have an outlet for a few hundred yards across the edge of the glacier (o, Fig. 3). Accordingly Col. Swanitz set his men to work cutting and blasting a channel in the ice. As much as four boxes of dynamite were set off at a time in blasting away the glacier, a task such as no engineer had probably ever undertaken before. After each blast, which hurled fragments of ice and stones hundreds of feet into the air, the men set to work with shovels and picks to remove the ice loosened by the discharge (Plate IX, a). The abundant water from the melting ice carried the ice blocks away after the channel assumed form (Plate IX, b), making it unnecessary to throw the ice out of the deep channel. The men in the channel had to be relieved frequently because they could not stand long in the ice-cold water, only a degree or two above the freezing point.

The authors found this phase of the work of the engineer's force at the ice channel the most interesting, partly because it is quite unique. In no other way have we ever before gained such a vivid impression of the vast magnitude of a glacier as when we saw and heard the explosions of hundreds of pounds of dynamite (Plate II, a), and watched a score of men busily digging away the loosened ice frag-

ments, with the sum total of a week's work a tiny scratch across a small part of the front of the glacier. The whole work of man was puny in contrast with the vastness of the great ice tongue. Against the hundreds of thousands of tons of ice, moving onward slowly but resistlessly, man could make but little progress. Yet the ice channel was completed and was quite adequate for its purpose.

*The Fosse.*—West of the ice channel the fosse between the glacier margin and the edge of the gravels required no improvement by man (Plate X). It was half a mile long (p-p, Fig. 3), fifteen or twenty feet deep, and led nearly to the bridge (q, Fig. 3), by which the corrected stream was to cross the railway.

*Completion of the Stream Diversion.*—All of the work outlined above was carried on simultaneously and, when the ice channel and the lower dam were completed, the walls at the upper end of the box canyon were hurled down in one giant blast and the stream was diverted from its old channel and successfully turned into the new one during the last week in June, 1911.

UNFORESEEN FACTORS IN THE DIVERSION.—Several unforeseen factors came out when the diversion was accomplished,[4] each one, however, tending to make the stream adjustment more satisfactory.

When the rock walls of the box canyon were blasted down the ice in the adjacent portion of the glacier was severely shattered and broken. Accordingly the stream from the little lake held in by the upper rock dam did not flow all of the way along the glacier margin, as was anticipated, but disappeared beneath the glacier for eleven hundred feet. The lake was quickly drained and at its upper end a hole (Plate XI), at least one hundred feet in depth was produced, into which all of the drainage of the northern margin of the glacier disappeared.

The second partly-unforeseen factor was the behavior of the stream at the ice channel. Instead of merely flowing in this channel and enlarging it laterally as Col. Swanitz anticipated, the stream rapidly cut down until it broke into the subglacial channel whose course we had traced with the dye, forming an ice canyon fifty-five feet deep which was rapidly enlarged by the stream (Plate XII). Six hundred feet of the channel was subglacial and the rest was a great open canyon in the ice. Col. Swanitz assisted nature with dynamite where it seemed desirable, but left most of the lower subglacial channel leading to the fosse, not thinking it necessary to unroof it since it carried away ice blocks as large as a small cabin without being blocked.

Between the last of June and the first of November, 1911, four hundred and fifty feet of the roof of this subglacial section of the

[4] We ourselves did not see all of these but were informed concerning them by later correspondence with Col. Swanitz.

stream was removed by erosion and melting, leaving only one hundred and fifty feet of roofed channelway. The larger portion of the ice channel, which was superposed upon the original subglacial channel, was cut down to bedrock, forming an ice canyon forty to sixty feet deep.

The new channel crosses the railway under a two hundred and sixty foot bridge in a single stream one hundred and sixty-five feet wide, five to ten feet deep, with a velocity of eight miles an hour and seemed to be deepening rather than filling its channel throughout the summer of 1911. The channel was deepened two feet from July to November.

Permanency of the Stream Adjustment.—Up to November 1, 1911, the diversion of the glacial stream was a thorough success. It is impossible to say how many years such an adjustment of heavily loaded glacial drainage may continue, but we see no reason to suspect that it should not continue as long as the glacier is in a stage of relatively-slow forward motion, accompanied by recession of the margin by melting. It is certain that the accelerated rate of recession of the ice edge, which this interference by man will produce, will also bring about the supply of much more water than normal during the summer months. This should result in erosion rather than aggradation by the glacial stream, provided it is deeply enough entrenched in its new course so that it cannot escape over the surface of the outwash gravels or break out in a new subglacial course at some point in the portion of the outwash fan still underlain by ice.

Col. Swanitz states that the Spencer Glacier retreated markedly in the summer of 1912, that the subglacial channel choked up in August, 1912, but that the stream broke out a new and lower outlet.

Great credit is due Col. Swanitz for his brilliant campaign against this glacial stream. Costing far less than the unsuccessful diversion by the dikes, it takes advantage of a series of naturally favorable conditions which a less gifted engineer might not have been able to utilize. It is to be hoped that this shifting of the glacial drainage may remain established for many years to come.

Possible Improvement of Railway Location.—Many of the difficulties in connection with the grade of the Alaska Northern Railway upon the alluvial fan of Spencer Glacier might have been avoided by crossing the streams a little to the north and farther from the glacier, where aggradation is less rapid and where the interference with stream flow by the piles and bents of the bridges would be less liable to result in upbuilding by the streams. Col. Swanitz informed us in 1911 that it would be possible to relocate the whole section of railway near Spencer Glacier by descending from the hanging valley in a new grade on the western valley wall. This would not only avoid the worst glacial streams but would take the railway out of reach of

an advance of Spencer Glacier (a) in the present precarious course over the terminal moraine (Fig. 3) and (b) in the section through the northernmost tunnels which extend within the barren zone.

The loop, spiral trestle, and tunnel near Bartlett Glacier on the pass are also in a very dangerous proximity to a glacier, and as the grades at the pass are very steep and the snow slide problem a bad one it may eventually be desirable to relocate the pass section of the railway near Bartlett Glacier, as well as that near Spencer Glacier.

If the expense of these two relocations is ever considered, it may eventually seem desirable to take up a new route for the Alaska Northern between Turnagain Arm and the Pacific Ocean. In this connection the following considerations are of importance.

The railway route is unusual in two respects (Fig. 1). It leaves tidewater and traverses the whole length of the Kenai Peninsula, crossing two passes and reaching tidewater again at the head of the Turnagain Arm of Cook Inlet. The reason that the seaport Seward is utilized rather than some harbor on Cook Inlet itself, is involved with the swift tides, the storms, and especially the winter condition of ice-covered sea in Cook Inlet. Accordingly, although it is over one hundred miles farther to the Seward terminal, this harbor is used because it is free from sea ice the year round.

The second respect in which the Alaska Northern railway is unusual is that the present, long, mountainous line to the Seward seaport was built at a cost of about $5,000,000,[5] rather than a much shorter line from the head of Turnagain Arm to a good harbor on Passage Canal in Prince William Sound (Fig. 1). This would have saved over fifty miles of railway but would have involved one expensive tunnel. The pass which leads from Turnagain Arm to Prince William Sound is now occupied by a glacier which advanced and filled this pass some time between 1794 and 1880.[6] If before 1794 a railway had been built through this ice-free pass, which rises only slightly above sea level, it would have been covered by over one thousand feet of ice in the subsequent advance of the Portage Glacier, which now occupies the pass.

Another short line for a railway between these same points, by a slightly longer route from Passage Canal through a valley not occupied by glaciers,[7] has many advantages and certain disadvantages in con-

[5] Brooks, A. H., Railway Routes in Alaska, Nat. Geog. Mag., Vol. XVIII, 1907, p. 185; Bull. 442, U. S. Geol. Survey, 1910, pp. 29-30.

[6] Martin, Lawrence, Jour. Geol., Vol. XIX, 1911, p. 458.

[7] See report on the longer of the two short routes from Passage Canal. E. F. Glenn, Reports of Explorations in the Territory of Alaska, 1898, War Dep't., Adj. Gen. Office, No. XXV, 1899, pp. 103-104;

Luther S. Kelly, Ibid, pp. 289-293;

J. S. Herron, Explorations in Alaska, 1899, War Dept., Adj. Gen. Office, No. XXXI, 1901, pp. 11-17.

nection with snow slides and with the glacial streams which flow through the valley.

We feel certain that, including the cost of the long tunnel, a railway only eleven or twelve miles long and practically at sea level could have been built from Passage Canal to Turnagain Arm for much less than the $5,000,000 used in the construction of sixty-five miles of railway from Seward to Turnagain Arm. This would have resulted in a marked saving of grades, a saving of distance, and an elimination of nearly all of the glacier complications which still threaten the Alaska Northern Railway. If the government does purchase and extend this railway it may still be cheaper to adopt the Passage Canal terminal, as could possibly be done with the shortest route and the longest necessary tunnel for less than $2,000,000.

The harbor in Passage Canal was shown by soundings taken by the junior author in 1910 to be quite as good for ocean steamships as Resurrection Bay, upon which Seward is located. Practically no icebergs float into Passage Canal or Prince William Sound from Port Wells. The possible disadvantage in this respect could never be as great as that which will come to Seward if the Bear Glacier (Fig. 1), at the mouth of Resurrection Bay on the western side, advances a quarter to a half mile and sends floating icebergs into the path of the ocean steamships there. The maximum possible activity of the glaciers tributary to Passage Canal and to the head of Turnagain Arm could never be such a menace to the building and maintenance of a railway, as are the Spencer and Bartlett Glaciers on the Alaska Northern Railway, particularly if the railway were protected by a tunnel in the critical area of snow slides and glaciers near Passage Canal. The Bartlett Glacier, though now inactive, could, by a very moderate advance, completely block the northern pass across the Kenai Mountains. Indeed, the railway goes so close to the glacier that even the slightest of advances will do great damage. The Spencer Glacier constitutes an even greater danger to the railway, as has been described on the preceding pages.

Other Glacial Stream Complications in Alaska.—That the foregoing is not a unique case of man's struggle with glacial streams is indicated by the following specific cases from other parts of Alaska. At the town of Valdez, where a glacial stream has several times done considerable damage to property, dikes of piling have only resulted in temporary relief. The latest of these raids by the glacial stream came in the summer of 1911. At Castner Glacier, in the Delta Pass across the Alaska Range, traffic was interrupted at the time of our

[a] Although each of these officers except Mr. Kelly reported adversely on this for a government mail route it is well worth considering for a railway with a tunnel, though to our mind not as good as the shorter direct route, with a tunnel in the mountain wall immediately north of Portage Glacier.

visit in the summer of 1911 because the powerful glacial stream shifted out from under a government bridge. At Kennicott Glacier during the same summer several piles were removed from a railway bridge by a swift glacial stream, a common experience along the Copper River.

Certainly the engineers of the Alaska Northern Railway have now acquired a knowledge of and a respect for glacial streams, as have many others in Alaska. Nevertheless, the respect is not yet adequate. We have never seen mention, for example, that there are grave, glacial stream problems in connection with the proposed railway from Controller Bay to the Bering River coal field. The many streams from the great Bering Glacier, a piedmont ice tongue nearly as large as the Malaspina, might make this route entirely impracticable for a railway. We ourselves should regard the glacial stream problem at Controller Bay as a factor not inferior to the harbor problem. We should feel gratified if the publication of this paper would prevent the building of any more railways or roads in Alaska before adequate consideration is given to the adjacent glaciers and the glacial streams. Because the Copper River and Northwestern Railway, for example, has not yet had grave difficulties with the streams of the Sheridan, Allen, Heney, and Kennicott Glaciers there is no assurance that the next year or two may not bring forth railway problems as grave as those which the Alaska Northern has had to cope with at Spencer Glacier, where the railway engineer so skillfully accomplished the diversion of the glacial stream described in this paper.

Annals of the Association of American Geographers
Volume II, pp. 41-48, Plates XIII-XVI

# THE LOCAL DISTRIBUTION OF THE REPTILE-AMPHIBIAN FAUNA IN SOUTHERN VERA CRUZ AND ITS BEARING ON THE ORIGIN OF THE SAVANNAHS

ALEXANDER G. RUTHVEN

CONTENTS



Statement of the Problem.—Several explanations have been given for the grass-land areas, or savannahs, in Middle America. Most of these explanations are based on natural conditions, such as climate, soil, etc., but O. F. Cook[1] has recently asserted that such areas have been artificially cleared by the methods of agriculture practiced by the natives and kept so by burning. Cook gives several kinds of evidence to support his assertions, most of them having to do with reforestation.

Another line of evidence may throw light on the problem. If the grassland areas are natural they are also, with little doubt, old and should, it would seem, have a characteristic fauna. If they have been deforested in relatively recent times they should have an impoverished fauna. In 1910, the writer made a study of the reptile-amphibian fauna of an area in southern Vera Cruz, in the course of which information was obtained on this subject.[2]

General Description of the Region.—The region investigated was the low plain at the foot of the San Andreas Tuxtla Range, in the canton of Acayucan. The country lying between the San Juan River and the San Andreas Tuxtla Mountains, at the Hacienda de Cuatotolapam, which received most of our attention, is a low, gently rolling plain. According to Mr. H. B. Reese, Assistant Chief Engineer of Construction of the National Railroad of Mexico, the elevation of the banks of the San Juan River at the proposed crossing near

[1] Cook, O. F., Vegetation Affected by Agriculture in Central America. Bull. 145, U. S. Dept. of Agric., Bur. Plant Industry, p. 8.

[2] For a detailed report upon the reptiles and amphibians see Zool. Jahrb., XXXII, Abt. f. Syst., pp. 295-332.

the hacienda is fifteen meters. The most conspicuous elevations on this plain are the groups of Indian mounds along the streams.

The streams traversing the region, Arroya Negra, La Laja Creek, Hueyapam and San Juan Rivers, are tributaries of the last named river. These streams all have a low gradient soon after leaving the mountains, and flow rather sluggishly through a bed of debris. Owing to the level nature of the topography the drainage is rather poor. On the higher ground there are numerous shallow ponds, some of which are doubtless dry except during the rainy season. They were all filled with water during the summer. The ponds are mostly small, and apparently not usually over a meter in depth.

East of the flood plain of the Hueyapam River the land rises rapidly to the foot hills of the mountains. In the heart of the range lies the Laguna de Catemaco, one of the few large lakes in the Republic.

CLIMATE.—The region lies within the tierra caliente of Hann, and Calvert's[3] zone III, the zone characterized by a mean annual temperature of 68°-77° F. The nearest stations where meteorological observations have been made are San Juan Evangelista (88m) and Acayucan (158m). According to the table given by Calvert, the mean annual temperature for a period of five years is, for the former 74.3° and for the latter 76.1°. It is safe to conclude that the mean annual temperature of Cuatotolapam is very close to 75°. This places the region climatologically (cf. Calvert's map) very near to zone II and it might be considered to be intermediate between this zone and zone III. According to the residents, the hottest months are April and May, and the coldest January and February. We recorded the temperatures for forty days at Cuatotolapam (July 10 to August 18), and these may be summarized as follows: highest 94°, on August 4; average maximum 89.4°; lowest 61.5°, on July 22; average minimum 71.6°; greatest daily range 28.5°, on July 22; average daily range 17.7°.

It will be seen from these data that the summer temperature is not excessively high, and that the daily range and the variation from day to day are relatively small.

There are two well marked seasons,—the wet season from July to October inclusive and the dry from November to June. We were informed that it rarely rains at all from January to the middle of the year. The greatest rainfall is in the month of September. In 1910 it rained on twenty-seven of the forty days between July 10 and August 18, and owing to the poor drainage the streams became greatly swollen, the water accumulated everywhere between the low elevations, and there were numerous ponds on the savannahs, conditions that probably characterize each rainy season.

[3] Calvert, Philip P., Proc. Acad. Nat. Sci. Phila., 1908, pp. 473-478, Pl. XXVI.

Vegetation and Habitats.—The region supports the savannah type of forest and grassland described by Schimper (*Plant Geography*) and Schomburgk (*Reise an Britisch-Guiana,* Theil III). Along the streams there is a luxuriant forest growth, characterized by large trees and an abundance of lianes and epiphytes (Plates XIII, a, and XIV). On the higher ground this forest is replaced by grassy savannahs dotted with groves of stunted trees (Plate XV). These groves vary in size from a few trees to thickets several acres in extent, the trees when solitary showing the umbrella form described by Schimper (Plate XV, b).

From the standpoint of the amphibians and reptiles seven major habitats may be recognized in the region studied.

*Lowland Forests.*—The dense jungle that naturally occupies the law ground. The trees are large and form a dense shade (Plates XIII, a, and XIV).

*Lowland Forest Clearings.*—These are the grass-grown or thicket-covered areas that have resulted from the clearing of the lowland forests. The cultivated fields are included here (Plates XIII, b, and XVI).

*Lowland Forest Ponds.*—The pools that occur throughout the jungles during the rainy season.

*Rivers and Lakes.*—All of the streams—San Juan, Hueyapam La Laja, and Arroya Negra—are included here. The animals considered characteristic of these bodies of water are both aquatic and semi-aquatic forms (See table, pages 44-45).

*Savannah Forests and Thickets.*—The areas of woodland on the higher parts of the plain. These may consist of rather extensive forests or be limited to a few trees or to areas covered with low bushes (Plate XV, b).

*Savannah Grassland.*—The grass-covered areas on the higher parts of the plain, and surrounding the patches of savannah forest. Where studied, the grass was kept short by grazing (Plate XV).

*Savannah Ponds.*—Numerous shallow ponds dot the savannah, and these all contain water during the rainy season. The largest pond investigated was the Laguna de Chacalapa which is roughly a mile long by one-half mile wide and less than a meter in depth everywhere except where a ditch has been dug at one end.

Local Distribution of Reptiles and Amphibians.—The local distribution of the species is given in tabular form and may be summarized as follows:

1. Of the thirty-two species only five—two terrestrial and three amphibious—are found on the grassland proper. Two of these are

| General Distribution | Savannah Habitats | | |
|---|---|---|---|
| | Grassland | Ponds | Woods |
| Common to savannah and forests or rivers and lakes | – – – – – – | – – – – – – | 2 (rather common) |
| | 1 (infrequent) → | → | 4 {(2 common) (1 infrequent) (1 rare)} |
| | 3 {(1 infrequent) (2 rare)} → | 5 {(3 infrequent) (2 rare)} → | 1 (infrequent) |
| | – – – – – – | 1 (rather common) | – – – – – – |
| Total | 4 | 6 | 7 |
| Peculiar to one habitat | – – – – – – | – – – – – – | – – – – – – |
| | 1 (rare) – – – | – – – – – – | 2 (rare) |
| | – – – – – – | 1 (infrequent) | – – – – – – |
| | – – – – – – | – – – – – – | – – – – – – |
| Total | 1 | 1 | 2 |
| Number of different species in each habitat | 5 | 7 | 9 |
| | 9 | | |

| Habits | Distribution of Different Species in Forest and River and Lake Habitats | Total Number of Different Species |
|---|---|---|
| Arboreal or arboreal and amphibious | 0 ———— cleared<br>2 —— common —— uncleared<br>0 ———— rivers and lakes | |
| Terrestrial | 2 —— common —— cleared<br>common<br>2 —— infrequent? —— uncleared<br>0 ———— rivers and lakes | |
| Amphibious or amphibious and terrestrial | 4 —— common —— cleared<br>common<br>1 —— common —— uncleared<br>0 ———— rivers and lakes | |
| Aquatic | 0 ———— cleared<br>0 ———— uncleared<br>1 —— common —— rivers and lakes | |
| | 12 = 11 in forest and 1 in rivers and lakes | |
| Arboreal or arboreal and amphibious<br>Terrestrial<br>Amphibious or amphibious and terrestrial<br>Aquatic | 8 in forest     8 in rivers and lakes | 32 |
| | 8     8 | |
| | 19     9 | |

infrequent and three are rare (one being found nowhere else), and four are shared with the lowland forest. Seven species—six amphibious and one aquatic—are found about the ponds, but only one is rather common, while four are infrequent and two are rare (one not being found elsewhere), and five are also found in the forest and one in the rivers and lakes. Considering these two habitats together, as they can not easily be separated, there are nine species—two terrestrial, six amphibious and one aquatic—only one of which is fairly common, while five are infrequent and two are rare, and seven of these are shared with the forest and one with the rivers and lakes, two being peculiar.

2. The savannah woods and thickets have nine—two arboreal, six terrestrial and one amphibious—of the thirty-two species. Only four of these can be called common, while two are infrequent and three are rare. Seven species are shared with the forest, two of these also with the grass-land, and two are peculiar.

3. Twenty-eight species—six arboreal or arboreal and amphibious, eight terrestrial, six amphibious or amphibious and terrestrial, and eight aquatic—occur in the lowland forests and rivers and lakes. Sixteen of these are not found on the savannah, and the twelve that are shared with the savannah habitats are all common here.

Before discussing the results shown by this table its probable incompleteness should be pointed out. In the first place, it goes without saying that there are more species in the fauna than the thirty-two given. This will affect the general results but little, however, for it is believed that very few of these will be found on the savannah. It is also very probable that some of the forest forms other than those indicated will on further investigation be found on the savannah, but this will also have little effect on the general conclusions, for the fauna was studied carefully, and if other forms occur on the savannah it is but rarely, they will be more numerous in the woodland, and their occurrence will be offset by the fact that three of the four forms only found on the savannah will with little doubt also be found in the forest. Again, one may safely predict from their habits that all of the forms of the grassland will be found in the savannah woodland and in greater abundance. It is thus believed that further work will not disturb the general relations indicated by the data obtained, and which may be expressed as follows:

1. The reptile-amphibian fauna of the savannah grassland is very meager both in species and individuals, and consists principally of amphibious forms (and aquatic if the abundance of the one pond species, crocodile, is considered) which are more numerous about the ponds. Only two strictly terrestrial forms were observed in this habitat and these were infrequent.

2. The savannah woodland has a more extensive fauna than the

grassland, having as many species and many more individuals than the grassland and ponds together, and the increase is due to the addition of terrestrial and arboreal forms from the forest. It probably has all of the amphibious species found on the grassland, so that a complete census will show more species than on the grassland and in the ponds together.

3. The forests and rivers and lakes have three-fourths and probably all of the species found on the savannah (woods, ponds and grassland) besides a relatively very large number of peculiar forms.

Conclusions.—The distribution of the reptiles and amphibians as just summarized may be interpreted as follows: There are two groups of natural habitats in the region—the forest and the rivers and lakes. To these have been added the lowland clearings and the higher clearings now known as savannah grassland, and so recently that no characteristic fauna has developed. When the lower lands are cleared many of the ground and semi-aquatic forms persist; the former in the rank grass or in the cultivated fields, the latter in the ponds. If the land is higher and extensively cleared and grazed some of the ground forms may still linger in diminished numbers in the savannah groves that were not destroyed or have reformed and many of the amphibious and aquatic species also in small numbers in or about the ponds; but the grassland areas constitute conditions so different from those to which even the ground forms from the forest are accustomed that very few forest species persist and these only in very small numbers, while the land has not been cleared long enough for the development of a prairie fauna.

The apparent recentness of the grassland makes it probable that the clearing has been done by man, but the faunal data do not of course throw light on this point. However, as Cook[4] says, "To invoke other than the human agencies to account for the present lack of forests in many parts of Central America is superfluous, for the destructive abilities of the Indians are everywhere in evidence. Reforestation is everywhere going on, but the Indians are also busy cutting down and burning the woody vegetation. If the burning over of the land were limited to areas ready for planting the general results would be far less disastrous, but the fires are usually allowed to spread wherever there is fuel to carry them, and large tracts of land are thus kept in a permanently barren condition." Fires are not, however, the only factor in maintaining the grassland. When once deforested the land, at least in southern Vera Cruz, is excellent for grazing purposes, and thousands of cattle now roam over the savannah and have done so for many years.

Finally, it should be pointed out that this paper discusses the conditions of a single restricted area. It is possible that the so-called

[4] Cook, O. C., loc. cit. p. 8.

savannahs of Middle America have not had a common origin. The principal object of this paper is to point out the peculiar distribution of the reptile-amphibian fauna and the fact that this can be easily explained on the theory that the savannah is of recent origin.

ANNALS OF THE ASSOCIATION OF AMERICAN GEOGRAPHERS
Volume II, pp. 49-54, Plate XVII

# ON THE PROPER MAP FOR DETERMINING THE LOCATION OF EARTHQUAKES

WOLFGANG L. G. JOERG

CONTENTS



INTRODUCTION.—A seismogram, when properly interpreted, allows of the determination of the seat of the earthquake whose tremors it has recorded.[1] The elements required in this determination are the direction and the distance of the earthquake from the given seismological station. These elements are best expressed graphically, viz., on a map of the world showing azimuth lines radiating from, and circles of distance drawn about, the given station as their center. The main requirement of such a map being that it indicate any azimuth from a given point, a projection belonging to the group of azimuthal projections should be used. The stereographic projection will be found to be the best.

NECESSITY FOR INVESTIGATION: PREVIOUS WORK.—Attention is called to this fact because seismologists have often followed the example set by Grablovitz in his maps of the world showing azimuth and dis-

[1] It becomes increasingly apparent that, contrary to former belief (cf. A. Sieberg: Handbuch der Erdbebenkunde, 1904, pp. 292 and 300), the registrations of a *single* station are sufficient for the determination of the epicenter. Cf. B. Galitzine: Sur la détermination de l'épicentre d'un tremblement de terre d'après les données d'une seule station sismique, *Comptes Rendus de l'Acad. des Sciences,* Vol. 150, 1910, pp. 642-644, 816-819; and paper on the same subject by the same author in the *Comptes Rendus des Séances de la Troisième Réunion de la Comm. Permanente de l'Assoc. Internat. de Sismologie,* Zermatt, Aug. 30-Sept. 2, 1909; also W. Schweydar: Bestimmung des Azimuts des Erdbebenherbes an den Registrierungen auf einer Station, *Petermanns Mitteilungen,* Vol. 57, II, 1911, pp. 326-327.

tance from various stations on Mercator's projection.[2] The maps recently published by von Müller[3] and Nakamura[4] are instances of this. The inappropriateness of Mercator's projection for this purpose has been dwelt upon by de Kövesligethy,[5] but his words seem to have been little heeded. Well aware of the necessity of selecting an azimuthal projection de Kövesligethy suggested the use of the equidistant projection of this group, often styled Postel's projection. This choice is entirely correct in principle and reveals a far greater appreciation of the requirements of the problem. Nevertheless, Postel's projection is, for practical reasons, not as well adapted to the purpose under consideration as is the stereographic projection, as will be shown later. For the present the inappropriateness of Mercator's projection will be considered.

Statement of Problem.—The problem is this: to superimpose upon the existing geographic coordinates of the globe a new system of spherical coordinates having the given seismological station and its antipodal point as its poles. In this system the meridians are represented by the azimuth lines, the parallels by the circles of distance. For convenience azimuth lines coinciding with every two points of the compass (intercepting, therefore, angles of $22\frac{1}{2}^\circ$ each) are usually selected together with circles of distance whose spherical radii are $9^\circ$ or multiples thereof, because of the practical equivalence of $9^\circ$ and 1000 kilometers.

Solution by Means of Mercator's Projection.—In order to represent this system of coordinates on a map of the world on Mercator's projection one must determine the position, expressed in terms of geographic coordinates, of the intersections of the azimuth lines with the circles of distance. This involves, for the number of coordinates referred to above, not less than seventy[6] distinct calculations by the

[2] *e. g.* G. Grablovitz: Weltkarte der Azimute und der Entfernungen für Laibach, *Die Erdbebenwarte,* Vol. 4, 1904-05, p. 171, Laibach [Carinthia], 1905. Similar map for Rome in the *Boll. della Soc. Sismologica Italiana,* Vol. 7, 1901-02, opp. p. 226.

[3] Länge und Richtung der Luftlinien von Stuttgart aus in Mercatorprojektion [equatorial scale 1:75,000,000] berechnet und gezeichnet von A. v. Müller, Regierungs-Baumeister. Accompanies, as Tafel 43, note by same author, *Petermanns Mitteilungen,* Vol. 56, II, 1910, pp. 263-264.

[4] Azimuth and Distance from Tokyo. [Mercator's projection: equatorial scale 1:100,000,000]. Accompanies, as Plate XV, "On a Map Showing the Azimuth and Distance from Tokyo" by S. Nakamura, *Journ. of Geogr.* (Tokyo), Vol. 23, 1911, pp. 327-330. (Fig. 1 is a tracing of this map.)

[5] R. de Kövesligethy: La meilleure mappemonde sismique, *Comptes Rendus de la Réunion de l'Assoc. Internat. de Sismologie,* The Hague, Sept. 21-25, 1907, p. 147.

[6] There are 320 points of intersection in all. Because of the fact that the meridian of the earthquake station and the E-W line are axes of symmetry, the remaining 250 points of intersection can be deduced by analogy without further calculation.

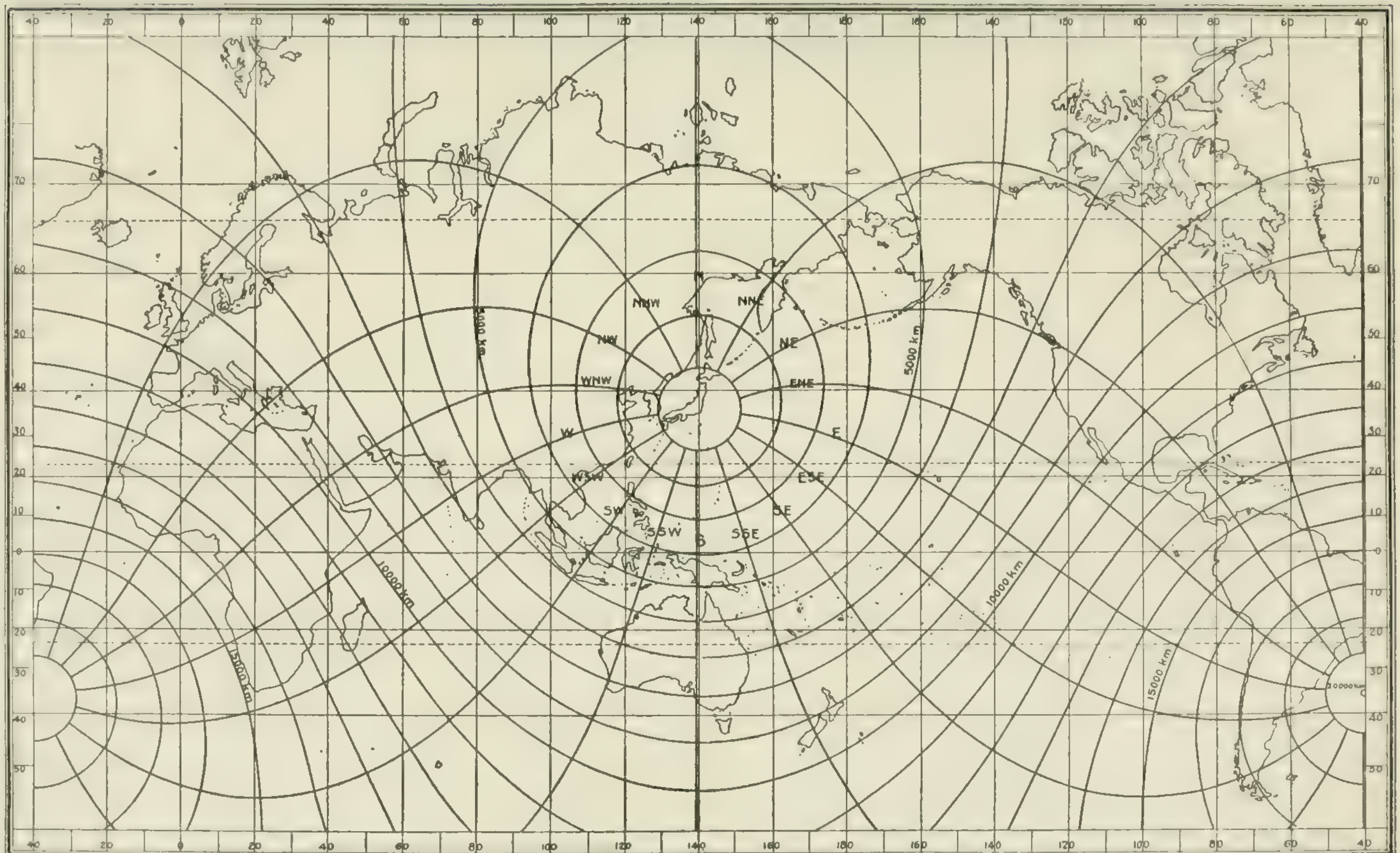


FIG. 1—Azimuths and Distances from Tokyo, Japan, on Mercator's Projection. Equatorial scale 1:225,000,000. Traced and reduced from Plate XV, *Journ. of Geogr.* (Tokyo), Vol. 23, 1911.

use of Napier's Analogies.[7] As the accompanying diagram (Fig. 1) shows, the curves resulting from joining these intersections are, due to the principle underlying the construction of Mercator's projection, far from simple: the circles of distance assume the form of ellipses which gradually grow larger as they extend outwards from their respective common foci until they open up into transitional parabolic curves, while the azimuth lines become irregular curves joining the earthquake station with its antipodal point.

Solution by Means of the Stereographic Projection.—To represent the required system of coordinates on the stereographic projection it is merely necessary to construct a map of the world on this projection. On it the azimuth lines and circles of distance resolve themselves into the fundamental net-work of all azimuthal projections and (Plate XVII) assume the form, respectively, of straight lines radiating from, and concentric circles drawn about, the earthquake station and its antipodal point as their respective common centers.

Comparison of Both Projections: (a) *as to Construction.*—The main difference, then, between the two solutions of the problem is that the new system of coordinates in the one case has to be calculated while in the other it is constructed.[8] The former procedure is far more lengthy and tedious than the latter, although using the stereographic projection involves the construction of the projection in its entirety, while maps of the world on Mercator's projection, on which the azimuth lines and circles of distance can be plotted, are usually available in printed form—the main reason for their general use. The stereographic projection, however, is not difficult of construction. Its meridians and parallels consist of arcs of circles. Furthermore it is one of the few azimuthal projections that can be drawn practically without any previous calculation. No reference can here be made to its construction; details can be found in any standard treatise on projections.[9]

(b) *as to Inherent Appropriateness.*—But, even if it were easier to plot the superimposed system of coordinates on Mercator's projection than to construct a stereographic projection, the stereographic projection should be chosen nevertheless because of its greater inherent appropriateness. On it, in view of the fact that, as already mentioned, the azimuth lines are straight lines diverging from a common

[7] Tables, in part incomplete, given in the papers by Grablovitz, v. Müller and Nakamura, cited above.

[8] The net-work of the stereographic projection can, of course, also be computed. That it can be constructed geometrically is due to the fact that this projection also belongs to the group of perspective projections.

[9] *e. g.* Leitfaden der Kartenentwurfslehre by K. Zöppritz and A. Bludau, Part I, third edition, Leipzig, 1912, pp. 67-72 and 92-97, or kartenkunde by E. Gelcich, F. Sauter and P. Dinse, third edition revised by M. Groll, Leipzig, 1909, pp. 37-54.

center, any given azimuth can directly be laid off by means of a protractor while on Mercator's projection interpolation between the different azimuth lines is, in general, very difficult and, on account of the distortion, practically impossible within 22½° of the N-S line, as will be apparent by referring to Fig. 1. Furthermore the usual maps of the world on Mercator's projection do not represent the Polar Regions, a decided lack because of the seismic importance of the Antarctic Continent with its active volcanoes Erebus and Terror and because of the probable continuation in it of the Andean geanticline.

Solution by Means of Postel's Projection: Comparison with the Stereographic Projection.—Referring now to Postel's projection, the use of which was advocated by de Kövesligethy, it will be remembered that its use was stated to be entirely correct in principle. It, too, belongs to the group of azimuthal projections. In this group it is the representative of the property of equidistance while the stereographic projection is that of equiangularity (orthomorphism). On it, therefore, the circles of distance are drawn with radii of proper proportional length, and distances from the earthquake station can be directly laid off on it. On the stereographic projection, due to the principle underlying its construction, the circles of distance are not drawn thus, the interval, for instance, between the 9,000 and the 10,000 kilometer circles being twice as large as that between the station and the 1,000 kilometer circle. On this projection, therefore, distances cannot be laid off directly. However, the necessary interpolation is not difficult as, for all practical purposes, the radial distance between two consecutive circles can be considered a unit and proportional interpolation used. In addition to the advantage just mentioned, Postel's projection, in common with the stereographic projection, allows of the direct laying off of azimuth angles, for, although its character as an equidistant projection excludes its being at the same time equiangular as a whole, it possesses this property for the only point for which it is required in the present problem, viz., its central point, so that from this point any azimuth can be laid off.

In contrast with these points in its favor Postel's projection has the disadvantage of not being easy of construction. Not only does it not lend itself to being drawn without the aid of calculation, but on it meridians and parallels are not, as they are on the stereographic projection, arcs of circles but arcs of ellipses, which are more difficult to draw.[10] All things being considered, therefore (including the rela-

[10] A graphic comparison of the stereographic with Postel's projection is afforded by the diagram of a hemisphere drawn to the same scale on the equivalent (Lambert's), the equiangular (stereographic) and the equidistant (Postel's) azimuthal projection superimposed upon each other, which accompanies "Zur Abbildung der Halbkugeln" by A. Bludau, *Zeitschr. der Gesell. für Erdkunke zu Berlin*, Vol. 30, 1895, pp. 406-416.

tive unimportance in this case of the fact that the stereographic projection is not equidistant), it cannot but be said that the stereographic projection affords the best solution of the problem.

Solution by Means of Wire Spherical Coordinates Over a Globe.—In conclusion attention may be called to the fact that a "laboratory" solution, as it were, of the problem under discussion would be possible by constructing out of wire a system of spherical coordinates, of the intervals previously mentioned, which could be fitted snugly over a globe. If its poles were fixed on the globe at the positions of the earthquake station and of its antipodal point this simple device could serve as a permanent means of determining the location of any earthquake from a given station.

Summary.—The problem of determining the seats of earthquakes by means of seismograms, then, allows of various solutions. Aside from the "laboratory" method of using a wire system of coordinates fitted to a globe three graphical solutions have been discussed. The use of Mercator's projection, while involving no difficulties of construction because usually available in printed form, is totally inappropriate; Postel's projection, while affording a solution entirely correct in principle, requires calculation for its construction and is not easy to draw. The stereographic projection, even with the slight disadvantage of not having equidistant azimuth lines, is otherwise correct in principle, requires no fundamental calculations for its construction and is easy to draw.

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Addendum to Notes 2 to 5. Attention should also be called to several papers published, in part, since the above was written, which offer two other solutions of the present problem. These are: (a) by O. Klotz: (1) Earthquake Epicentres, *Journ. Roy. Astron. Soc. of Canada*, Vol. 4, 1910, pp. 172-178; (2) *id.*, *Bull. Seismol. Soc. of Amer.*, Vol. 1, 1911, pp. 143-148; (3) *id.*, Appendix No. 1, *Report of the Chief Astronomer*, 1910, pp. 44-48 (Dept. of the Interior, Ottawa, 1912); (4) Über die stereographische Methode zur Herdbestimmung von Erdbeben, *Beiträge zur Geophysik*, Vol. 11, 1912, pp. 501-514; (5) Stereographic Projection Tables, *Journ. Roy. Astron. Soc. of Canada*, Vol. 5, 1911, pp. 205-215; and (b) by G. W. Walker: Graphical Construction for the Epicentre of an Earthquake, *Geophysical Memoirs*, Vol. 1, Part 1, 1911, pp. 53-54 (Meteorol. Office, London, 1912).

Klotz's method (developed in his papers 1, 2, 3 and 4, above: tables in 4 and 5) presupposes a knowledge of the distance of an earthquake from at least three stations; Walker's that of the distance and the azimuth from a single station only. Both Klotz's and Walker's methods make use of the principle of the stereographic projection, not, however, to construct a map, but as the basis for a graphical solution of the calculations involved. They differ from the present method in that they must be separately applied for each new determination, while the map, once constructed for a given station, represents a permanent solution for all determinations from that station.

ANNALS OF THE ASSOCIATION OF AMERICAN GEOGRAPHERS
Volume II, pp. 55-64

# INDUSTRIES OF WISCONSIN AND THEIR GEOGRAPHIC BASIS

R. H. WHITBECK

CONTENTS



GENERAL INTRODUCTION.—In a paper read before this society four years ago, it was pointed out that only two of the twenty-four chief lines of manufacturing in the State of New Jersey used, to any considerable extent, raw materials produced within the State. To such a condition, the State of Wisconsin presents a striking contrast. Taken together the two states illustrate how the manufactures of a region increase in diversity, and in their independence of local raw materials, with the development of the region. Also that geographical influences themselves undergo a progressive change, and that factors which exert a strong influence at one stage of a region's development may lose their significance later.

AGRICULTURE AND DAIRYING.—Only one-third of the land of Wisconsin is actually improved. One-half of the land is more or less wooded. In ten northern counties an average of only one-tenth is in farms (1910). Some millions of acres are cut-over and burned-over timber lands, awaiting development. The best farming region is in the south and southeast on the glacial and residual limestone land which sells at from one hundred to two hundred dollars an acre.

The most conspicuous agricultural development is dairying. As a producer of milk, Wisconsin now leads all the states.[1] Cheese factories and creameries have passed three thousand in number.

A study of this industry reveals the following facts:

[1] January 1, 1912, Wisconsin was credited by the United States Government report with 1,504,000 milch cows, and New York with 1,495,000.

1. That there are few cheese factories or creameries in the northern part of the State, due to the lack of development of this region.

2. That cheese factories are lacking and creameries are few in seven counties in the central portion of the State, due to the sandy soil, unfavorable to the growth of grass and hay.

3. That practically all the three thousand cheese factories and

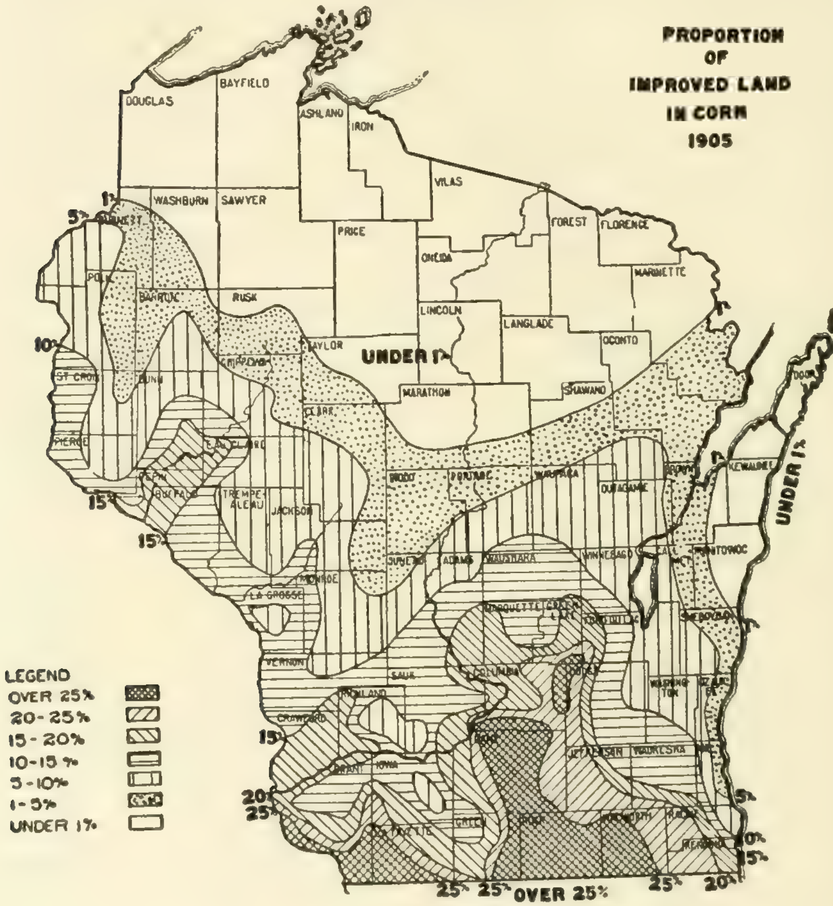


Fig. 1.

creameries are on residual clay or glacial clay loam whose water retaining capacity favors pastures and meadows.

4. That the creameries occupy the corn belt; that creameries are a response to winter as well as summer dairying; that corn in the form of ensilage is the economical winter feed for cows, and that the corn belt closely coincides with the region of 150 days growing season, and that in this belt cheese factories are unable to meet the competition of butter factories.

5. That the cheese factories almost monopolize a region near Lake Michigan and another in the rougher and higher lands of the west-southwest; for cheese-making is a response to summer dairying, prospers where the weather—especially the nights—are cool, and hence where corn growing is less important.

6. That there are few cheese factories in Wisconsin south of the mean summer isotherm of 70°.


Fig. 2.

7. That Wisconsin is the main center for the making of Swiss cheese, chiefly produced in the Swiss settlements in the southern part of the State; that Swiss cheese is more sensitive to soil and climate than any other kind; that the Swiss factories are on land of nine hundred to one thousand feet in altitude; that 95% of the two hundred and seventy-five factories are on limestone land, and that 90% of the one hundred and six factories making Limburger cheese are grouped in the low valleys on sandstone land.

8. That northern Wisconsin, with clay loam soil and cool climate, promises to develop into another great cheese-making section.

9. That Wisconsin's dairy products now amount to eighty million dollars annually, have doubled in ten years and are greater than those of New York, heretofore the leader.


FIG. 3.

10. That this trend toward dairy farming is most beneficial to the agricultural interests of the State.[2]

The geographer is in danger of overlooking non-geographic factors. The great prosperity and the rapid development of the dairy industry

[2] For much of the data on dairying, including figures 1, 2 and 3, the writer is indebted to Professor A. R. Whitson and Mr. O. E. Baker of the College of Agriculture, University of Wisconsin.

in Wisconsin can not be explained alone on the basis of geographic causes. Certain men—conspicuously ex-Governor Hoard—and an institution—the agricultural college of the State University—through their continuous campaigns of education, have been very important factors in the growth of this industry. Natural conditions made profitable dairying possible; a well directed policy of education brought it to its present high development.

The Lumber and Timber Industry.—When the white man came to Wisconsin, thirty million acres of timber lay untouched before him. In those forests stood more than one hundred billion feet of white pine and as much more of other merchantable timber. At the close of the Civil War, enough white pine stood in Wisconsin to liquidate the national debt which that war had piled up. All of the gold mined in the United States from 1792 to 1900 ($2,300,000,000) would not, at present prices, buy the lumber that stood in Wisconsin's forests. All the gold ever mined in California would not pay for the lumber still uncut in Wisconsin. All the gold mined in California last year would be required to pay the wages of the men employed by the lumber companies during one average year between 1890 and 1900 when the industry was at its height.

Among those pines were trees that scaled five thousand board feet, lumber worth to-day two hundred dollars. There were townships from which four hundred million feet of lumber were cut, and single acres from which one hundred thousand feet of white pine were taken, an amount which would now cost a Madison builder four thousand dollars.

A few years ago a thousand saw mills were at work; five hundred or six hundred are still at work, and some of them cut thirty million feet of lumber a season. The value of the lumber cut annually, even in these days of decline, is five or six times that of all the zinc and iron annually mined in the State. In 1900, one-fourth of the wage earners engaged in all lines of manufacturing in the State were engaged in the manufacture of lumber and timber products. The interests which centered in this gigantic industry built up towns and cities, extended railroads, controlled legislation, made millionaires and for a time joined hands with the railroads in directing the political destinies of the state. Except the soil, no other natural resource has had such bearing on the material development of Wisconsin as have these enormous forests.

Three related facts—all matters of geography—have been effective influences in the exploitation of these forests:

1. The plain-like character of the state, making lumbering easy.

2. The radial flow of its rivers, their torrential character in spring, and their available water power.

3. The two important waterways, the Great Lakes and the Mississippi River, on the borders of the state.

Wisconsin's rivers flowing outward in all directions, giving excessive transporting power in spring by the melting of the heavy snows, and affording water power at frequent intervals, lend themselves ideally to the purposes of the lumbermen. Furthermore, these rivers lead


**Fig. 4.—Distribution of cities in Wisconsin. Size of circle is in proportion to the size of city.**

directly to the Mississippi and to the Great Lakes, which in their turn lead to the populous East or to the treeless prairie states, regions forming the great lumber markets of the Union.

To appreciate how geographical advantages in Wisconsin hastened the appropriation of its forest wealth, it is only necessary to note that its forests, though one thousand miles from the Atlantic seaboard, were well exploited before extensive lumbering operations were

even begun in West Virginia. Logging and the cutting of rough lumber reached its height in the years around 1895. During these years there were, at single favorable places on the main rivers, eight, ten, twelve or even more lumber mills, the largest of them capable of sawing upwards of five hundred thousand feet a day. The choice timber is now far back from the streams; railroads have replaced rivers as


FIG. 5.—Distribution of lumber centers in Wisconsin.

transporters, and fewer mills of greater capacity and located at favorable points, are doing the work.

During the last decade and a half, an evolution in the wood working industry has been in progress, an evolution which is of interest chiefly because it illustrates a principle of industrial geography. The earlier mills simply cut logs into rough lumber. The finishing and further shaping was done elsewhere. But the timber supply diminished

and the mills had to stop or change their methods. In many instances lumbermen owned valuable rights, they owned homes and property at these places which could not be moved and could not be sold at their value. These men knew the sources and qualities of wood. The white pine was nearly gone, but spruce, hemlock and hardwood remained. The mills of northern Wisconsin have been gradually turning to the manufacture of more highly finished products and to the utilization of other kinds of wood than pine. It is the evolution of an industry in response to diminishing or changing raw materials.

Upwards of fifty mills now make sash, doors, blinds and interior finish. Twenty-five mills make wooden packing boxes from defective lumber. Seventy-seven mills turn out cooperage. Fifty mills make vehicle stock and forty make woodenware. Twenty-eight make agricultural implements and more than one hundred make furniture. Fifty pulp and paper mills have sprung up along the rivers, particularly on the Fox and upper Wisconsin. Three-fourths of all the water power now used in the state are employed by the paper and pulp mills. The lower Fox is lined with them. Appleton alone has nearly a dozen.

In the city of Sheboygan, 57% of the wage earners are employed in the furniture factories—chiefly chair factories. Almost every town of any size in the northern half of Wisconsin finds its industrial life centered around wood working. Many, perhaps a majority, of these mills have grown up quite independent of connection with the earlier lumber mills. On the other hand many of them are the lineal descendants of those mills.

A further modification of the principle is seen in the manufacture of vehicles and vehicle stock, originally based on the abundance of timber. The supply of raw material has diminished and yet the industry increases, reshaped in response to changing conditions; in several notable instances merging into automobile factories.

An interesting offshoot of a wood-using industry is found in the city of Ashland, the Lake Superior port for the Gogebic iron range. Here is located a wood distilling plant. An unavoidable by-product is charcoal, produced in very great quantities. What was to be done with it? Train loads of iron ore were daily entering Ashland. Why not use the charcoal in smelting ore? A smelter was established and now iron smelting is a side line of a wood distilling plant.

Paper Making.—In paper making another principle of industrial geography is illustrated. Most of the pulp and paper mills were established to utilize Wisconsin wood. Now only about one-half of the pulp wood comes from the state and this proportion will continually decrease, but the manufacture of pulp and paper will probably continue, for the mills are established, water power is developed,

capital, experience and skilled labor are localized. The industry is rooted. For lack of a better phrase, I have called this familiar principle, *The persistence of a rooted industry.*

THE PEARL BUTTON INDUSTRY.—The persistence of the pearl button factories in one or two towns along the Mississippi River in Wisconsin, illustrates the same principle. These factories were established to utilize the enormous quantities of clam shells obtainable in the upper Mississippi. But the local supply of shells diminished and now a part of the supply is brought by train to these factories from rivers many miles away. But the industry persists, though the original cause is only partially operative.

THE TANNING OF LEATHER.—In the tanning and finishing of leather, Wisconsin forms one of the quartette of leading states, and Milwaukee leads all cities. This industry was of course intimately connected with the supply of oak and hemlock bark, though chemicals are now used.

Such is the influence of the natural resources of the State upon some of its chief manufactures, namely, butter and cheese, lumber and timber products, wood pulp and paper and the tanning of leather.

CONCENTRATION OF INDUSTRIES ON THE GREAT LAKES.—An additional point which calls for mention is the notable concentration of manufacturing at one point, the city of Milwaukee situated on one of the Great Lakes; the value of its manufactured products equals that of the next twenty cities all taken together. In fact one-third of all the manufactured articles produced in the state are produced in this one city. Milwaukee and its neighbors, Racine and Kenosha, also on Lake Michigan, have quite outgrown their dependence upon the state's raw materials and are responding to other stimuli—particularly the ever-growing demands of the expanding Middle West.

The comparative value to the state of the two waterways on its borders—the Mississippi River and Lake Michigan—comes out strikingly in the fact that ten manufacturing cities have grown up on the shore of the lake and only two on the Mississippi, and the larger of these two ranks only sixth among the manufacturing cities of the state. While eight hundred thousand people live in the counties touching Lake Michigan and its arm, Green Bay, only three-eighths of that number live in the counties touching the Mississippi and its branch, the St. Croix. Ten out of eleven counties on Lake Michigan have gained in population during the past decade, while six out of eight on the Mississippi have lost. Furthermore, the effect of growing urban population in stimulating agriculture in the surrounding region, is shown by the fact that rural population during the last decade, has increased in every one of the Lake Michigan counties except two, while

the rural population has actually declined in every Wisconsin county on the Mississippi River.

Two generations ago the Mississippi was considered to be a very important factor in the industrial development of the state. That railways should connect the interior counties with the Mississippi was regarded as quite as important as that they should connect them with Lake Michigan. The earliest railway in the state was built from Milwaukee westward to Prairie du Chien on the Mississippi River. Great things were expected of the Green Bay and Western Railway, which was built to connect Green Bay with the Mississippi, but the road is still merely a cross-country line.

The great cities just outside of the state,—Chicago, St. Paul and Minneapolis,—have effectively dominated the direction of the great arteries of commerce in Wisconsin.

Wisconsin has no coal and its expansion in manufacturing will ever be bound up with the problem of fuel. Coal from Buffalo is laid down at the docks of Milwaukee and other Lake Michigan ports in Wisconsin with a freight charge of only thirty-five to forty cents a ton. For a very short haul inland from these ports, the railways charge double this amount. This single factor of the low freight rate on coal to Lake ports, must continue to work effectively in their favor as against the towns in the interior of the state.

Summary.—Summarizing the geographical influences which have helped or hindered the industrial development of Wisconsin, it is evident:

1. That its northerly location, placing it in the great northern forest belt and giving it a wealth of timber, which has been the greatest single influence upon manufacturing, is the foremost factor. But that this same condition has retarded the general development of the northern half of the state. That the cool climate combined with the clay soil—both limestone-residual and glacial—and the stimulus of educational efforts, have made Wisconsin the foremost dairying state.

2. That the extensive woodworking industries are passing through an evolution in the direction of producing more highly finished products in response to diminishing supplies of raw material.

3. That the most effective localizing influence so far as manufacturing is concerned is Lake Michigan, while the Mississippi has largely lost its importance.

4. That the great difference in freight rates on eastern coal to inland cities of Wisconsin as compared with lake ports is reacting strongly in favor of these ports, and must continue to do so.

5. That the position of Wisconsin between the cities of Chicago, on one hand, and Minneapolis, St. Paul and Duluth on the other, has given a north-west and south-east trend to its trunk line railways which has completely supplanted the earlier east-west trend given by the effort to connect the Mississippi with Lake Michigan.

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# THE NOATAK RIVER, ALASKA*

PHILIP S. SMITH

CONTENTS



LOCATION.—Noatak River is in the northwestern part of Alaska. It empties into Kotzebue Sound, an arm of the Arctic Ocean, at about 162° 30′ W. longitude, and its most remote headwaters rise in the highlands in longitude 155° W. The greater part of its course is, roughly, along the 68th parallel.

PREVIOUS EXPLORATIONS AND MAPS.—The first map indicating a large river in approximately the position of the Noatak was published by Simpson[1] in 1855. Dall, however, when he summarized the state of knowledge regarding Alaska, as late as 1869, says concerning the Noatak (which he called the Inland River) and certain other streams in northwestern Alaska: "They are small unexplored streams. They are prolonged far into the interior to fill up the unexplored spaces on most maps."[2]

S. B. McLenegan, of the U. S. Revenue Cutter Service, was the first to make a survey of the Noatak. In 1885, with a single companion, he started up the river in a skin boat. By hard work he reached what he called the head of canoe navigation at approximately longitude 158° W. In reality this is nearly seventy-five miles air line, or more than one hundred and fifty miles by river, below the real head of canoe navigation. He returned safely and published a short account

* Published by permission of the Director, U. S. Geological Survey.

[1] Simpson, John, Surgeon, R. N. H. M. S. Plover, Observations on the Western Eskimo and the country they inhabit: Great Britain, Parliamentary Papers, session of 1854-55, Vol. 35.

[2] Dall, W. H., Alaska and its resources, p. 285, 1869.

of his trip, with a map. Although the geodetic positions shown are considerably in error, the form of the river is sufficiently accurate so that the larger features are recognizable.[3] The topography of the valley was much conventionalized and only crude hachuring was used.

During the winter of 1885-86 Lieutenant Stoney of the Navy and other members of his party crossed from their camp on the Kobuk to the Noatak, and one of them, Lieutenant Howard, continued across into the Colville basin, which bounds the Noatak basin on the north, and eventually reached the Arctic Ocean near Point Barrow. As a result of these trips a portion of the Noatak basin near longitude 157° W. was visited and partly mapped. Unfortunately, however, the report prepared by Stoney and his associates was lost and was never published. However, in 1900, owing to the growing interest in Alaska, he prepared a popular account of his travels accompanied by a map. This volume[4] was written without the complete data available and after the lapse of nearly fifteen years. Consequently, there are many discrepancies even between the text and the map.

Since that time prospectors have visited different parts of the basin, and there is even a government school for natives about fifty miles in an air line above the mouth of the river, but the only available information concerning the entire valley has been derived from the reports of Stoney and McLenegan.

Extent of Exploration by Author.—In 1911 a survey party, consisting of the writer, with C. E. Giffin as topographer and four camp hands, traveled by canoe from the Koyukuk River at the mission of St. Johns-in-the-Wilderness (near the former site of Bergman) up the Allen River, a distance of over two hundred miles, crossed the divide to the Noatak, and descended that stream to its mouth. As a result of this trip over ten thousand square miles were surveyed geologically and topographically, the larger part of this area being within the Noatak basin. The topographic mapping was carried on mainly by means of planetable surveys on a scale of 1:180,000, or approximately three miles to the inch, using an alidade with a micrometer attachment. For a stretch of about seventy-five miles in the low gravel flats in the central part of the Noatak valley, where other methods were inapplicable, a compass traverse was run, with distances measured by time. Every sixty to eighty miles geodetic position was determined by solar observations made with a light mountain transit.

History of Topographic Development.—Broadly stated, the Noatak basin is parallel to the general trend of a series of highly metamorphosed schists and allied rocks and less metamorphosed lime-

[3] McLenegan, S. B., Report of Cruise of the Revenue Marine Steamer Corwin in the Arctic Ocean in the year 1885, pp. 53-83, Washington, 1887.

[4] Stoney, G. M., Naval Explorations in Alaska, Annapolis, Md., 1900.

stones, sandstones, and shales. The structure of these various members is intensely complex, and the river by no means follows the structural details. The deformation by which the main drainage lines were initiated occurred so long ago that the various streams have had ample time to modify in large measure the constructional forms and to produce drainage rearrangements. After a stage of probably mature dissection had been reached Alpine glaciers were formed in the highlands and, gradually encroaching on the existing stream valleys, modified them. The limits of the ice have not been determined, for with the waning of glaciation great outwash deposits were produced that mantled most of the lowland areas, effectively concealing the previous topography. New drainage modifications were produced as a result of this cycle. With the nearly complete disappearance of glaciers, except in the more protected mountain recesses, the Noatak began the excavation of the gravel filling of the lowlands. At the present time it is flowing for the most part in a rather narrow steep-sided trench at varying depths below the top of the gravel outwash deposits. In this degradation bedrock was here and there encountered and rocky gorges appear.

Topographic Subdivisions.—It was not possible to investigate in detail the various geographic and topographic features, or even to gain an accurate impression of the basin as a whole. In fact, in places long range views failed to reach the limits of the basin, so that even such elementary facts as its area could not be determined. There seem, however, to be six more or less topographically distinct parts into which the region adjacent to the Noatak may be divided. These are from the mouth upstream, a coastal lowland, the Igichuk hills, the middle lowland, the second highland area, the third lowland, and the headwater mountains.

*Coastal Lowland.*—The coastal lowland adjacent to the Noatak, as its name implies, has low relief, at few places rising to more than a hundred or two hundred feet above the main stream. Presumably it is mainly of marine origin, as it has neither the form nor the structure of a normal delta. It merges with the narrow coastal plain to the west, although to the east no sharp line can be drawn between it and the Kobuk delta. Near the river the upland is fairly well-drained, but further away the surface is an almost untraversable morass in summer and a wind-swept waste in winter. Only a few tributaries enter the Noatak in this part of its course, and all of these are mere wet-weather streams. The main river is nearly a mile in width and shallow. Timber is absent except as a narrow fringe along the river near the northern margin of the province, and the uplands are devoid of all vegetation except grass and small plants. Bushes here and there flourish in the protected gulches. There are no settlements in this


FIG. 1—The Noatak River and portions of Northwestern Alaska. Stippled areas are highlands; white areas near route are lowlands. Base furnished by U. S. Geological Survey.

province within the area draining into the Noatak, though there are some farther west.

*Igichuk Hills.*—The part called here the Igichuk hills is a highland area about fifteen miles wide trending more or less east-west, with the higher points rising to elevations of fifteen hundred and two thousand feet. The river cuts through this range in a narrow gorge with practically no flood plains developed and ragged limestone points jutting into the river in fantastic pinnacles. High-level gravels and topographic forms up to an elevation of seven hundred feet above the stream show evidences of drainage changes in the recent past. The range is too narrow to afford any considerable run-off, and only two or three streams enter the river in this province, so that the entire Noatak basin is rather narrow. A few native huts are located here and there on benches along the river. The owners live mainly by salmon fishing or by hunting walrus and seal along the coast, but game is rather scarce and is becoming more so all the time. Timber forms a narrow fringe along the streams. The hillsides are covered with low bushes, which give place higher up to grasses and then to lichens, and these to bare rocks.

*Middle Lowland.*—The middle lowland portion is a broad gravel-filled basin bounded on the south by the Igichuk hills and on the east by the highlands, called by Stoney the Baird Mountains. On the north the middle lowland gradually narrows until the hills reaching the river give rise to the second highland area. Westward, a practically uninterrupted plain stretches away to the Arctic Ocean. This lowland is approximately forty miles long north and south and averages about thirty miles wide east and west. The main river in this part is a network of anastomosing streams occupying a strip of the valley floor about two miles wide with numerous lakes and swamps on either side. Side streams originating in the hills that bound the lowland flow on steep gradients until, entering the lowland, they lose velocity and meander in sinuous patterns across the tundra. The largest tributary from the east is formed by the streams from the Baird Mountains. It flows parallel to the Noatak until that river, swinging against the northeastern margin of the Igichuk hills, cuts out the lowland and permits the tributary stream to enter. Short streams only are received from the Igichuk hills, and but few tributaries are received from the west. From the north the Noatak received several good-sized rivers that rise in the mountains forming the divide between the Noatak and the Arctic Ocean. Many of the larger valleys have a glaciated appearance from a distance, but none were explored.

In the central part of the middle lowland, on a gravel bench above the river, are the Noatak mission and the Government School. This

is the largest settlement in the Noatak basin. At this place there are three or four white people and about fifty natives. Timber is sufficiently abundant for ordinary needs, but other supplies have to be brought up the river from Kotzebue (the nearest coast village in communication with the outside world) in native skin boats, the trip taking three or four days upstream and one or two down.

*Second Highland Province.*—In the second highland province the hills to the north and east of the middle lowland approach close to the river, and thus for seventy-five miles, airline, the Noatak is hemmed in by hills three to five thousand feet above the sea. The beginning of this province on the west is marked by a narrow rocky canyon in places five to seven hundred feet deep, caused by relatively recent drainage obstruction. The main river is from one-eighth to one-fourth of a mile wide. Although showing numerous sharp large-scale bends, the river does not meander and is in a relatively youthful stage. Flood plains have been developed in those parts where the river is intrenched in the gravel plains, but they are practically absent where the river is flowing over bedrock. The current is swift, and although there are no falls nor serious rapids, the necessity of frequent crossing from side to side for tracking (rowing being out of the question) would make the upstream journey difficult and tedious.

Few of the tributaries from the south head more than ten to fifteen miles from the Noatak, but several from the north were seen extending back for at least twenty-five miles, and their headwaters are even more remote. The Noatak basin in this province therefore appears to be unsymmetrical, with the divide nearer the river on the south than on the north. Many of the larger valleys appear to have been glaciated, but none of the ice has left evidence of having reached the main valley, though outwash deposits are pronounced.

There are no permanent settlements in this part of the valley, and it is seldom visited by natives except on trips to the game country farther up river. The last of the spruce was seen a few miles above the canyon, and there is none any further east in the entire basin. In its place willow and alder form the main sources of fuel and even these are by no means abundant.

*Third Lowland.*—Farther upstream the hills recede from the river and the last lowland province is reached. This is a gravel-filled basin sixty miles long and from ten to thirty miles wide. It is a monotonous plain broken here and there by lakes on the upland, with the Noatak intrenched from fifty to two hundred feet below the general surface level. In this part of its course the river, now one-eighth to one-sixth of a mile in width, shows a meandering habit, but blind sloughs and braided characters are rare, and the current is nearly three miles an

hour. Huge boulders, derived from the outwash deposits through which the stream has incised its course, form obstructions to all but canoe navigation.

Near the middle of this basin the largest tributary from the south joins the Noatak. It carries nearly one-half the volume of the main river above that point and drains a large area between the Kobuk and the Noatak. From the north also a large tributary, the Aneyuk, enters. This stream heads in the distant rugged mountains that mark the northern boundary of the Noatak basin. Many of the valleys tributary to the Aneyuk show broadly open U-shaped cross sections that were undoubtedly produced by former valley glaciers. A broad low pass leads from the Noatak by way of the lowland of the Aneyuk into the Colville basin, which drains northward into the Arctic Ocean. This was probably the pass traversed by Lieutenant Howard of the Stoney expedition on his trip to the Arctic coast.

This region appears to be an especially good caribou country, for many of these animals were seen ranging over the brushless rolling uplands and browsing on the abundant reindeer moss. Natives from downstream and even from the Kobuk make annual trips to this part to secure their winter's supply of caribou meat.

*Mountainous Headwater Province.*—The mountainous headwater province extends, roughly, for about seventy-five miles east and west. It forms the divide between the Noatak and north, south, and east drainages. Passes to these different basins occur at several places, and most of them are glaciated cols; for instance, the pass from the Noatak River to the Allen River on the east. This pass is only one thousand feet above the rivers, and the distance between the two streams is about eleven miles.

The mountains rise from five to six thousand feet above the river, or seven to eight thousand feet above the sea, and are intensely rugged and impressive. The floor of the main valley gradually narrows from a lowland two miles wide in which the river, about one hundred yards wide, meanders in a slightly intrenched gorge, until in the very headwaters it is entirely occupied by the stream. Gravel deposits up to an elevation of one thousand feet above the river form benches here and there that interrupt the steep bare rock scarps elsewhere prominent. The rocky walls rise abruptly from the valley floor and have a truncated appearance that is usually associated with glaciation. This interpretation is further suggested by the straight alignment of the various interfluves and the absence of long straggling spurs. Deep glacial erosion of the main valley however, is precluded by the numerous exposures of bedrock in the valley floor. There are still glaciers in the mountains, but they are at most only a few miles in length.

Game is abundant. Mountain sheep are particularly numerous in the high, less accessible parts. Natives from places a hundred or more miles distant make annual hunting trips to the headwater mountains. Gold has also been discovered in this part of the Noatak basin, but the inaccessibility of the region, the absence of timber, and the shortness of the open season have combined to prevent prospecting, so that there is no mining industry. There are no permanent settlements.

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# A GEOGRAPHICAL PILGRIMAGE FROM IRELAND TO ITALY

W. M. DAVIS

CONTENTS



The Pilrimage of 1911 and its Members.—The following pages describe an excursion which began in southern Ireland on August 1, and disbanded in northern Italy on October 5, 1911. It took the name of "Pilgrimage" because we visited many localities made famous in the history of physical geography by the work of masters in an earlier generation. The members of the Pilgrimage, of whom a list here follows, numbered thirty-two and represented fourteen countries. England, Scotland, Ireland and Wales being counted separately. Seldom did our party include more than ten of the total membership. Several student members are marked (St.).

H. O. Beckit, School of Geography, Oxford University, England.
Léon Boutry, University of Clermont-Ferrand, France.
Maurice Brienne, University of Lille, France. (St.)
Abel Briquet, Douai, France.

G. G. Chisholm, University of Edinburgh, Scotland.
G. A. J. Cole, Royal College of Science, Dublin, Ireland.
J. Cvijic, University of Belgrade, Servia.
James Cossar, Training College, Glasgow, Scotland.
W. M. Davis, Harvard University, Cambridge, Mass.
Pierre Denis, University of Paris, France.
Albert Demangeon, University of Lille, France.
Lucien Gallois, University of Paris, France.
Gilbert Garde, University of Clermont-Ferrand, France.
Ph. Glangeaud, University of Clermont-Ferrand, France.
Walter Hanns, University of Leipzig, Germany. (St.)
Amund Helland, University of Christiania, Norway.
Mark Jefferson, State Normal College, Ypsilanti, Mich.
O. T. Jones, University College, Aberystwyth, Wales.
Olinto Marinelli, Institute of Higher Studies, Florence, Italy.
J. E. Marr, Cambridge University, Cambridge, England.
Fritz Nussbaum, University of Bern, Switzerland.
Hans Praesent, University of Greifswald, Germany.
Giuseppe Ricchieri, Scientific and Literary Academy, Milan, Italy.
Alfred Rühl, University of Marburg, Germany.
Ludomir v. Sawicki, University of Cracow, Galicia.
Hans Spethmann, University of Berlin, Germany.
Aubrey Strahan, Geological Survey of Great Britain, London.
Antoine Vacher, University of Rennes, France.
Harry Waldbaur, University of Leipzig, Germany. (St.)
W. B. Wright, Geological Survey, Dublin, Ireland.
Fritz Wyss, University of Bern, Switzerland. (St.)
Naomasa Yamasaki, University of Tokio, Japan.

There was abundant discussion directed to the origin of the land forms in the districts visited, and to the best means of describing them; but, as is usually the case when geographers are gathered together, many diverse opinions and methods were developed. Even the object and scope of our work were differently interpreted by the various members. Nevertheless there was a general acceptance of explanatory in preference to empirical methods for geographical descriptions; and frequent employment was made of the scheme of "structure, process and stage" for the description of land forms, though with greatly varying proficiency and completeness. There was an interesting diversity of opinion in such problems as the origin of certain truncated uplands which we visited, some members ascribing them to marine denudation, others to subaerial degradation; hence this problem is discussed with some fullness on a later page. Frequent dissent was expressed from my principle, that geological formation-names, indicative only of geological dates in past time, ought to be

excluded from purely geographical descriptions, since geography has to do only with the present. Some of the liveliest discussions arose when comparisons were made of one-page descriptions of a limited area that we had examined together; the order of the statement and the emphasis given to different elements varied greatly, in spite of the fact that we had all seen the same things. All this shows how far we are still from having standardized our geographical methods.

Five Days in Ireland.—The pilgrims gathered under the valued guidance of G. A. J. Cole, Professor of Geology in the Royal College of Science, Dublin, and Director of the Geological Survey of Ireland, with whom we first examined some interesting features of glacial origin in the neighborhood of Killarney, among which were: the Gap of Dunloe, a good example of a "glacial distributary pass" in Sölch's classification—that is, one in which glacial overflow across a preglacial notch has shifted the crest of the notch up the glacial stream and at the same time lowered it; a well defined glacial amphitheater where the glacial distributary which deepened Dunloe gap ended on the plain to the north; and a beautiful example of a shore-terrace formed in the waters of a glacial-marginal lake which had its outlet at the head of the valley that it occupied—all these features being under investigation by Mr. Wright.

Then the great sea cliffs at the west end of Valencia Island were visited, where we admired the contrast between the normally rounded and soil covered forms of the landward mountain slopes and the sharply undercut precipices by which their seaward faces were characterized. From the top of these cliffs the sharpened peaks of the Skelligs were seen; they once presumably had rounded forms, but they have been so strongly undercut all around the shore line by the violent attack of the Atlantic waves that they are now steepened to the very summit. By no means all the length of the coast in the southwest possesses lofty cliffs; they occur only where the subrecent submergence of the lowlands, in the retreating border of which ragged cliffs of small height are cut, has been sufficient to bring the sea to the base of a group of subdued mountains. It was interesting to note that all the mountains were of complex anticlinal structure, while the lowland belts between them were deeply eroded synclines; thus contradicting the assertion often made that in greatly denuded folded structures, the synclines remain in relief, and showing that relief is more dependent on rock resistance than on folds.

Returning eastward we stopped at the elbow of the Blackwater, where Jukes, just fifty years before, first gave correct explanation to the relation of transverse and longitudinal, that is of consequent and subsequent, streams and valleys in tilted structures of varying resistance. This explanation was for a number of years overlooked

by observers in the United States, to the serious detriment of their work. We finally visited the ragged cliffs of the southern coast, where the successive development of cove, cave and slip appeared to be the regular order of progress in the vigorous attack of the sea on this immature coast line. Good exercise was found at the end of these few days in Ireland in attempting to compress an explanatory physiographic description of the district we had seen into as few words as possible; advantage being taken of a final day in Dublin to look up Jukes' famous article "On the Mode of Formation of Some River Valleys in the South of Ireland."[1] One of the experiments resulted as follows:

A Concise Description of Southwestern Ireland.—The heavy sedimentary strata of southwestern Ireland—the district referred to lies between Waterford on the east and Dingle Bay on the west—

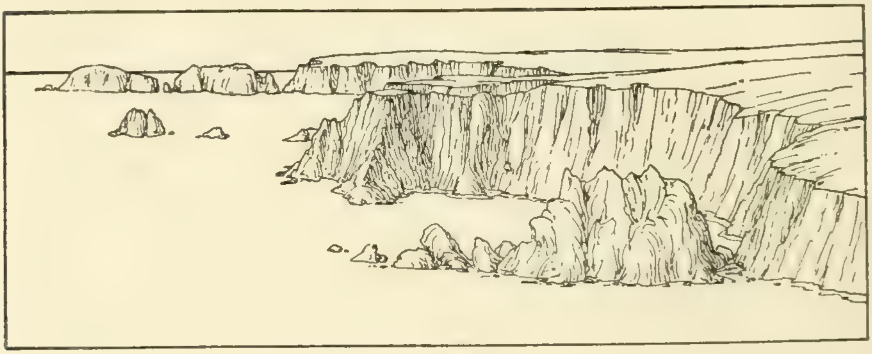

Fig. 1.—Sea cliffs near Great Newtown Head, about two miles west of Tramore, South Coast of Ireland, looking west.

were long ago compressed into complex folds trending north of east and south of west, and the region was then eroded to a late stage of the cycle thus introduced. The resulting lowlands, with numerous residual ranges and monadnocks which usually followed anticlines of resistant sandstones, were moderately uplifted with a gentle slant to the south; whereupon the synclines of limestone and slate were broadly excavated forming open rolling lowlands from three to ten miles wide and leaving the truncated anticlines and their surmounting residuals of the earlier cycle in discontinuous belts of irregularly dissected uplands and mountains. Some of the lowlands are trenched as if renewed uplift had revived their streams. The well adjusted drainage consists of transverse streams which cut through the uplands in narrow valleys and longitudinal streams which wander rather irregularly along the lowlands, receiving many branches from insequent ravines in adjoining higher belts.

[1] Quart. Journ. Geol. Soc., XVIII, 1862.

In the western part of the district the sandstones seem to be more resistant, as several complex anticlinal belts there remained in stronger relief at the close of the earlier cycle; they now, since the later uplift, have altitudes of from fifteen hundred to three thousand feet, with subdued forms of coarse texture, except where glaciated, as further stated below. The uplands and lowlands are nearly everywhere covered with a veneer of till that was formed in a widespread glaciation, and not with soil of local origin. Later local glaciation in the higher mountains excavated valley-head cwms, above which some of the crests are craggy; overdeepened the larger valleys within the ranges, thus producing oversteepened, plucked and scoured valley sides; and sometimes formed morainic amphitheaters on the piedmont lowlands, fronted with outwashed gravels, and more or less trenched and terraced. There are many cascades that fall from the highlands

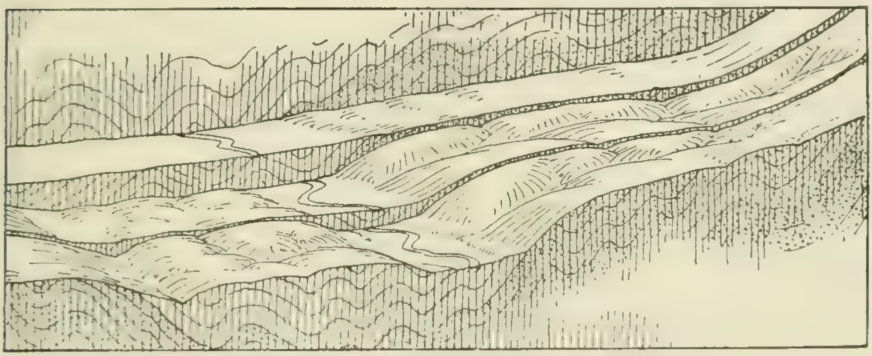

**Fig. 2.—Scheme of development for mountains, uplands and valleys of southern Ireland, looking northwest. First cycle, a peneplain interrupted by subdued mountains of the most resistant rocks in axes of anticlines; second cycle, excavation of broad valley lowlands along synclinal belts of limestone and contemporaneous submature dissection of uplands; third cycle, erosion of mature valleys in former lowland belts.**

into the cwms and from the cwms and hanging side-valleys into the main valley troughs; while the main streams on the trough floors are often broken by rapids. Lakes of small size or bogs representing former lakes, are common in the cwms; lakes occur also in the valley troughs and morainic amphitheaters, the best known of the latter kind being those of Killarney.

A depression of the region has led the sea into the distal parts of many valleys, thus forming the narrow transverse bays of the southern coast, of which the best known example is Cork harbor, and the wider longitudinal bays between the mountainous promontories of the southwestern coast, of which Dingle, Kenmare and Bantry are the largest. Very little wave work has yet been done on the inner shoreline of the bays; they are particularly irregular where the land

surface has been plucked and scoured by recent glaciation. The exposed outer coast has been cut back into ragged cliffs by the stormy sea; the cliffs being of moderate height where cut in the lowlands, but rising a thousand feet where the higher mountains have been attacked. Some of the subdued monadnocks of the earlier cycle, later converted

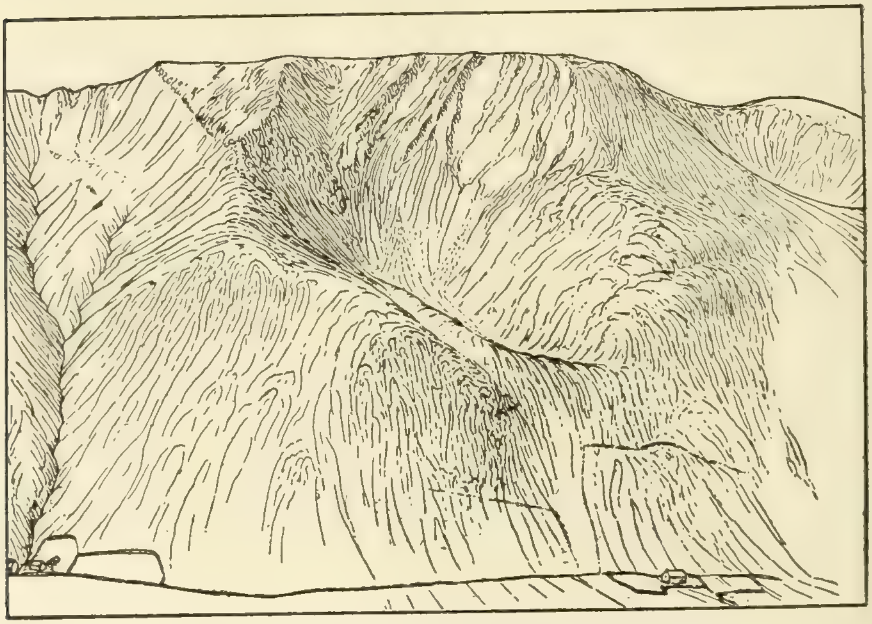

**Fig. 3.—A cwm in the side of the glaciated trough of Nant Francon (Beaver valley) near Bethesda, Wales; looking south. The rocks are steeply inclined slates, sandstones and lavas.**

into islands, have now been transformed into sharp peaks by "circumabrasion."

A Week in Wales.—Our next rendezvous was at Bethesda in North Wales, where a number of new members were gathered from England, Scotland, France, Germany, Norway, Galicia and the United States. Here under the amiable leadership of Dr. J. E. Marr of Cambridge University, we studied the effects of glacial erosion in modifying the normally subdued preglacial mountain and valley forms of the Snowdon district. As was the case on the Italian lakes in the summer of 1908, we had to regret that no one was present to maintain from conviction the inefficiency of glaciers as eroding agencies. A day on Snowdon was greatly enjoyed; the contrast of the deeply excavated valley-head cwms with the normally rounded summit and spreading convex spurs was very impressive. On both sides of the Snowdon mass we saw fine examples of glacially overdeepened troughs, with hanging lateral valleys opening in the side walls and

with rock steps and rock basins scoured in the floor. The lowering of preglacial passes by glacial cross-currents was noted at several points; the result in facilitating transportation through the mountains is here of evident economic importance on a small scale, as it is on a much larger scale along the line of the Canadian Pacific Railway across the Rocky Mountains and the Selkirks. As centers for the study of these typical features, Llanberis on the north and Snowdon Range on the southwest may be highly recommended.

Two half-days were profitably given, under the guidance of Professor O. T. Jones of the University College of Wales, to the uplands and highlands east of Aberystwyth, this being the region made classic by Ramsay's famous essay in which he brought forward his theory of the origin of certain plains by the marine denudation of moun-

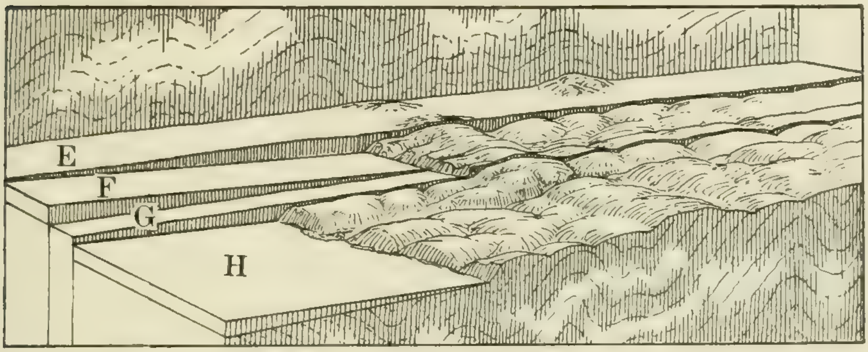


FIG. 4.—Scheme of development of highlands, uplands and coast line in west-central Wales, near Aberystwith; looking northeast. First cycle E, an extensive lowland of normal erosion or of marine abrasion, with occasional residuals. Second cycle, F, normal dissection of uplifted plain and encroachment on margin by marine abrasion. Introduction of third cycle, G, by elevation and withdrawal of sea. Third cycle, H, dissection of land area and encroachment on uplifted plain of marine abrasion by renewed attack of the sea.

tains. It was here a pleasure to find that our guide had made a new attack on this old problem, and had recognized two uplifted and dissected plains, separated by an escarpment, where Ramsay had seen only one; and further that he had good reasons for explaining at least the lower uplands as the result of marine denudation, a process that has been too generally neglected by British students since their recognition of the great value of subaerial degradation. Professor Jones has prepared a chapter presenting his views on central Wales in a publication that is unfortunately not easily accessible.[2]

On the first of our two half-days in Central Wales we saw a re-

[2] Souvenir of the Aberyswith Conference (National Union of Teachers), 1911. Edited by John Ballinger. Published by the National Union of Teachers, Bolton House, Russell Square, London, W. C., 1911.

markably fine example of a recent stream capture, about twelve miles inland from Aberystwith. The gorge down and up stream from the elbow is deep cut and steep sided; the side streams cascade on their descent into it, and the main stream at its bottom is not yet well graded. An excellent view up-stream (northward) across the elbow of capture is had from the railway station of Devil's Bridge, whence one may easily see the young gorge sharply cut in the mature valley floor.

The Even Upland of Lands End.—We left Wales for southern England, and on our way made an early morning visit to the incised meanders of the Wye, which like the uplands of Wales, are famous from Ramsay's early work. We went southward across Devonshire to Cornwall where the even upland near Lands End proved fruitful as a subject for explanatory description. Some regarded it as a plain of marine denudation; but the absence of cliffs on the exposed sides of several low monadnocks convinced the present writer that the upland was chiefly the result of subaerial normal erosion; although the occurrence of gravels containing marine fossils, reported by British observers, shows that the plain was submerged for a time after it had been worn down and before it was uplifted and dissected.

Let it here be explicitly stated that the discrimination between marine denudation and subaerial degradation in the production of the Lands End upland is rather a geological than a geographical problem, so long as it is concerned with the processes of past time. It becomes a truly geographical problem however, when it is shown that the present day forms of the surface would be of one kind if they had been formed by marine denudation, and of another kind if prepared by subaerial degradation; and still more geographical when the present-day forms of that interesting district are described in terms of the process by which it is believed they have been prepared. Of course the geological problem here touched is as worthy of attention from geologists as any other problem of past time; and it surely is open to investigation as a geological problem by geographers also, if they wish to investigate it; but geographers ought to recognize that this or any similar problem falls properly within their own province only when its solution is found to be helpful in describing things as they now exist.

In my own opinion the solution of this problem is geographically very helpful, because in my understanding of the case, plains of marine denudation and plains of subaerial degradation, uplifted and submaturely dissected, would not look alike, provided that the work done upon them before uplift had not gone so far as to wear all residual reliefs down to a featureless surface. The difference in appearance

of the two kinds of plains may be made clear by the following considerations:

Marine Denudation and Subaerial Degradation.—These two processes must go on together, one on the seaward side and one on the landward side of a shifting shoreline; and the area of sea-cut plain must, so long as the land mass stands still, gain on the subaerial area. Furthermore, in order that the sea-cut plain may gain a width of ten or twenty miles, the retreat of the sea cliffs at its landward border must be more rapid, probably very much more rapid, than the degradation of the land area, as shown in Fig. 5. When both processes are far advanced, the line by which their areas are separated

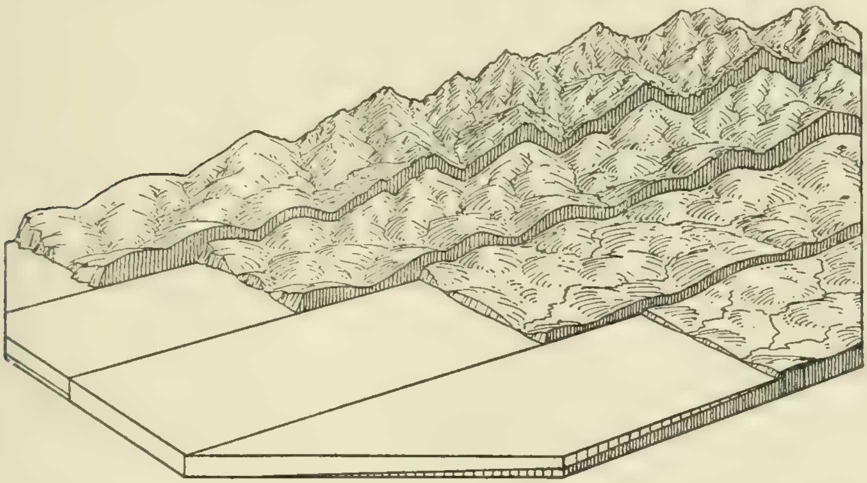

**Fig. 5.—Relation of normal degradation to marine abrasion; the horizontal encroachment of the latter being five or ten times the downward wear of the former. Development of sea cliffs of decreasing height in the advanced stages of marine abrasion.**

must be of relatively simple curvature, must be marked by low cliffs, and some of these cliffs must have been cut back of the low summit-arch of vanishing hills; consequently such cliffs may be described as of "decreasing height." A simple line of low cliffs, some of which are cliffs of decreasing height, is therefore an essential feature of the boundary between a so-far finished plain of marine denudation and a nearly finished plain of subaerial degradation, or peneplain. Hence this inferred line of cliffs may prove to be a valuable criterion in uplifted examples where the presence of massive rocks prevents discrimination by means of adjusted or unadjusted drainage lines. The boundary of an upland thus comes to have a value in determining its origin, and in giving it an explanatory description.

The less advanced a cycle of subaerial erosion, the more distinct should be the line of cliffs by which its area is separated from that of an adjoining area of marine denudation. It was the occurrence of a line of cliffs at the inner border of the lower uplands in central Wales, very similar, except for battering by weather and ravining by streams, to the line of uneven cliffs by which the same uplands fall off to the plain of marine denudation now in progress of making by the sea, that persuaded Professor Jones of the marine planation of the upland; and it was the uncertainty as to the existence of such cliffs around the residual monadnocks which still surmount the inner highland that left his hearers in doubt as to the origin of that earlier developed and more uplifted area. (See Fig. 4.)

If a district is described by an observer as an uplifted and partly dissected plain of marine denudation, the reader of such a description ought to have the right to infer that the writer of it had, before he wrote about it, seen a simple cliff-line, more or less battered by weathering, along its inner border. If on the other hand a district is described as an uplifted and dissected peneplain, this term being chosen so as to imply the subaerial degradation of the district in question, the reader has the right to infer that such mounds or monadnocks as rise above the general level are not bordered on their exposed side by cliffs or scarps. In other words, as soon as the discrimination between the two processes here considered is made in terms of their visible products, it has a definite value in aiding the description of an existing landscape; and thus understood the discrimination fairly enters the list of geographical problems. This matter is here repeated at some length, because when it was discussed during our Pilgrimage, it appeared to be novel to some of our party.

THE SEA CLIFFS OF CORNWALL.—The fine sea cliffs which abruptly terminate the uplands about Lands End were apparently the work of two attacks of the waves; first a rather well advanced attack, during or after which the cliffs gained a graded slope; then a lately renewed and vigorous attack, by which the base of the graded cliffs is sharply undercut in ragged and rocky forms, the platform in front of them not being yet widened enough to hold a beach, except in the larger coves. The amount of loss suffered by the uplands during the total retreat of the sea cliffs was carefully considered. The generally accepted idea is that the uplands once had a much greater extension seaward, and that they have been reduced to their present area entirely by marine erosion; but if such were the case the present coast ought to have the simple outline of maturity, while as a matter of fact its outline is decidedly irregular and immature. This suggests a moderate recession, less than a mile, as the result of marine attack on a not distant initial shore line of distinct slope, instead of a great

recession following an attack on a remote initial shore line where a gradual decline of the upland might lead it below sea level. Two possible explanations for a neighboring initial shore line of distinct slope were offered. One accounted for it by a differential faulting of the region after peneplanation, so that the sea began its attack on the fault scarp that separated the upfaulted from the downfaulted areas; but as it would require many intersecting faults of sub-recent date to produce a scarp only a mile or so outside of the present irregular shoreline, and as no traces of such faults are found on the remaining upland, this suggestion was rejected. The alternative suggestion was as follows:

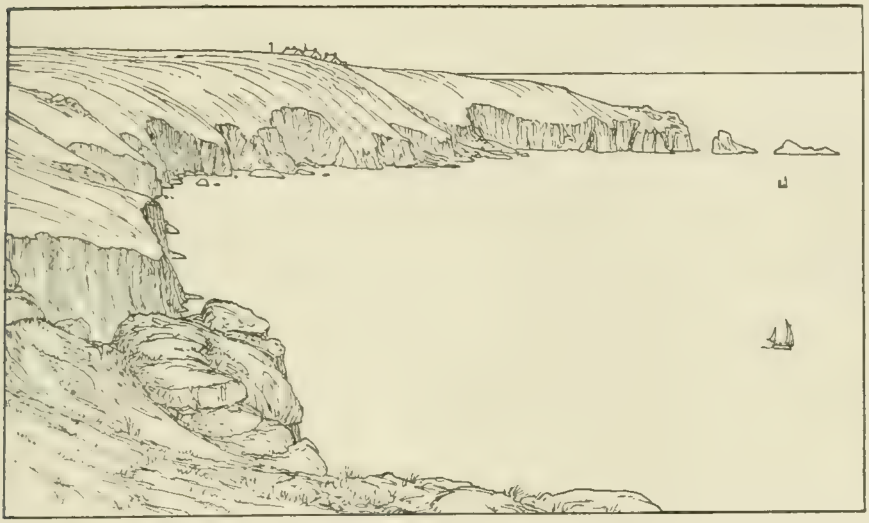

**Fig. 6.—The sloping cliffs of the Lands End upland, and the new attack of the sea at their base; looking south.**

A Round-about Explanation.—The deformed crystalline mass, of which Lands End and the greater part of Cornwall consists, was worn down to moderate relief, then depressed and buried under a heavy sedimentary cover; the compound mass was next unevenly uplifted and advanced to old age in the cycle of erosion thus introduced, so that the peneplain then formed traversed both the deformed older crystalline mass and the inclined strata of the sedimentary cover. The region was then rather evenly uplifted and the weaker covering strata were reduced to a new lowland or peneplain, while the resistant crystallines were only submaturely or maturely dissected; and in this condition the whole region was slightly depressed, so that the lowland of the new peneplain was submerged and the lower valleys in the dissected crystallines were drowned; thus the sea came to have its new shore

line on the slope which separates the crystalline uplands from the drowned lowlands, this slope being nothing more than a part of the ancient worn-down land surface that had lately been laid bare by the stripping of the covering strata from it between the levels of the two peneplains. The irregularity of the slope, and hence also of the initial shore line that contoured in consequent fashion around it, would depend partly on the inequalities of the ancient land surface, partly on the unevenness of its uplift after burial; and a moderate recession of such a shore line would produce the existing irregular shore line with its immature cliffs.

Several facts may be cited in favor of this somewhat elaborate explanation. First, the eastern or landward border of the Cornwall-Devonshire upland is determined by an irregular slope where the crystalline rocks, long ago worn down to an uneven land surface, depressed, buried, and uplifted, have been, after the peneplanation which produced the even surface of the present uplands, again uplifted and laid bare around their border by the lower peneplanation of the weaker covering strata; that is, the uplands are here bordered by precisely such a definite but irregular slope as is postulated, in the explanation under discussion, for the initial north, west, and south borders of the uplands. No shore line follows the eastern border, because the depression after the newer peneplanation was not sufficient to submerge that part of the bordering lowland. Second, the valleys by which the uplands are submaturely or maturely dissected are now all drowned in their lower courses, and thus transformed into branching bays of most typical form, as may be seen near Falmouth and Plymouth.

A curious difficulty was met in the discussion of this explanation, which deserves to be placed on record. The explanation was difficult to talk about because the structural "thing" that it involved had no simple name by which it could be easily mentioned; it had to be paraphrased, and the paraphrasing by different pilgrims varied greatly according as they emphasized one element of the "thing" or another, with the result of inconsequence and misunderstandings. We soon came to feel the need of some convenient term by which the roundabout paraphrasing could be avoided; and of this more will be said later.

THE UPLANDS OF DEVONSHIRE AND CORNWALL.—During the coming and going on our southwestward detour, we made brief stops on the north Devon coast, where the broad, coarse-textured highlands of Exmore descend abruptly to the shore of the Bristol Channel; on the north and south borders of the central highland of Dartmoor, so far out of the way and empty that an artillery camp is on one side of it and a large prison on the other; and on one of the beautiful

branching embayments that indent the southern coast,—the one that has Salcombe at its entrance and Kingsbridge at its head. After this brief inspection of the region it seemed to us all that its leading physiographical features could be concisely described as the products of two cycles of erosion on a disordered mass of crystalline rocks. The more even uplands of to-day, dissected by steep-sided valleys, are parts of the uplifted peneplain to which all but the most resistant rocks were reduced when the first cycle was interrupted by the uplift which introduced the second; while the large or small highland areas of broadly arched forms and coarse texture consist of the most resistant rocks, which therefore survived above the peneplain of the uplands as isolated or grouped monadnocks. On the other hand the districts of rolling hills with convex summits and with significant inequality of height, separated by well opened, late mature valleys, are areas of moderately resistant rocks, which were presumably worn to a smooth

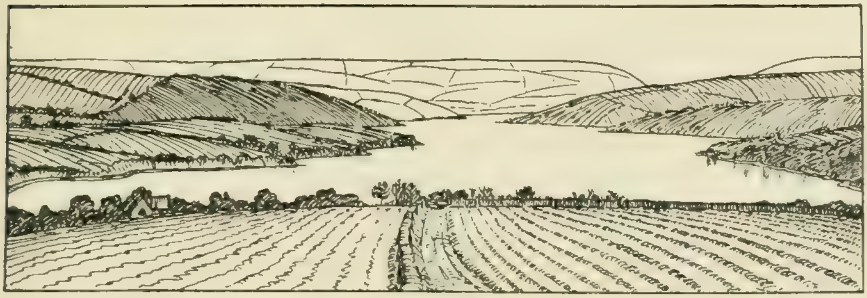

**Fig. 7.—A branching embayment entering the valleys of the late-mature uplands of southern Devonshire; looking south from near Kingsbridge toward Salcombe.**

plain at the close of the first cycle, and are now already advanced to a late mature stage of subdued forms in the recent cycle. If to this simple scheme, we add the conception of a bordering mass of weaker strata, now worn down to a new peneplain and recently submerged, as stated above, the chief features of the coast as well as of the interior may be understood. Some British observers have recognized levels of erosion or abrasion at several different altitudes, on which they base a more complicated scheme of morphogeny; but as far as our journey gave us a view of the region, the leading features are all referable to two cycles followed by a recent episode of slight submergence.

The Rarity of Cliffs of Decreasing Height.— In further evidence of the small retreat of the Devonshire-Cornwall coast, the rarity of cliffs of decreasing height deserves mention; that is of cliffs which have been, as above explained, cut back so far as to stand behind the broad crest of flat-topped hills into which the uplifted peneplain has

been dissected, so that with further recession they must lose height as the inland slope of the hill is consumed. Such cliffs ought not to be uncommon along a shore line that has been cut far back of its initial outline; they ought to be very rare or absent along a shore line that has been cut back but a little, less than a mile. They are certainly rare in Cornwall. The only one we saw stands not far west of Plymouth where a valley, trending for a stretch almost parallel to the coast, lies exceptionally near it. The rarity of decreasing cliffs seems to be one of the strongest reasons for concluding that the Cornish coast has not yet suffered a great retreat.

It may perhaps be objected that, if the uplands of Devonshire-Cornwall had really been surrounded at a little distance outside of their present border by an inclined series of covering strata, some remnants of such strata ought somewhere to be found, either clinging to the present coast, or standing forth as small islands. If this objection is fair, then the postulate, that the basal members of the covering strata are weak must be incorrect. Now it does happen that along the southern part of the eastern border of the Devonshire uplands, the covering strata are red sandstones and conglomerates of sufficient strength to have as yet escaped the peneplanation that has already overtaken the weaker shales and marls farther north; hence to this extent the postulate that the covering strata are weak is not justified. The stronger sandstones rise in hills, some of which do cling to the uplands of crystalline rock, but these are exceptional. Fragments of the sandstones might be looked for on the sea floor along the southern coast. Since my return home, I have found that such fragments have been dredged south of Plymouth.*

The South Coast of England.—On leaving Devonshire we followed the south coast where it transects the middle and upper members of the heavy series of covering strata, dipping gently eastward, and hence overlying the weak basal members on which the lowland bordering the Devonshire uplands has been worn down. The middle and upper members, although stronger than the lower ones, are evidently less resistant than the crystalline mass of Devonshire-Cornwall, for their now isolated uplands are separated by many broadly opened, late mature valleys; and along the coast the uplands are evenly truncated by smooth cliffs with beaches at their bases, and the cliffs are all strung along a comparatively simple line. This shows a good advance toward maturity of the marine cycle as here developed, in contrast to its immaturity on the ragged coast of more resistant rocks in Cornwall.

* R. H. Worth, Journ. Marine Biol. Assoc. United Kingdom, V. 1897, 381-387; Ibid., VIII, 1908, 118-188. See also patches of sandstone along coast; Geol. Surv. Gr. Brit., sheets XX, XXI XXII, XXIII, XXIV, XXVI.

It was interesting to note, as we crossed some of the uplands near the south coast, that they are covered with gravel; and this we took to indicate that the uplands are parts of a peneplain, presumably of the same peneplain which we had already seen better preserved in the uplands of crystalline rocks farther back. Local features of interest on the coast were the great landslips near Axmouth, the greater part of which occurred in 1839, described and figured by Conybeare; and the Chesil bank, a superb beach or reef of pebbles which stretches in a long sweeping curve from southeast to northwest, concave to the sea, and which attaches the former island of Portland to the mainland.

The Island of Jersey.—Weymouth harbor lies inside of the Chesil bank. There we took steamer to Jersey, and spent a profitable day walking over the well smoothed peneplain and along the fine cliffs of that tidy island. A broad platform of ragged rocks, laid bare on the southeast of the island when the strong tide ebbs, was a striking feature. There can be no question that, what with frequent storms and strong tidal currents, the abrasive action of the sea, always well supplied with gravel and sand, is intensely active on such a platform; and that the attack of the high-tide storm waves at the base of the cliffs is violently effective in cutting them back wherever they are reached. But violent as the marine action is here, we are not therefore constrained to conclude that a great recession of the cliffs and a great diminution in the area of the island have already resulted from it; for time, as well as violence, is a factor of this problem; and of the time that has elapsed since the island took its present attitude with respect to the sea, we are not well informed. In any case the irregularity of the shore line was such as to recall the inference we had made in Cornwall as to the small measure of the cliff retreat. Hence Jersey, and probably the other Channel islands as well, if explained in view of this inference, should not be regarded as small remnants much reduced by marine attack from a once large and continuous land area, but as moderately reduced masses of fundamental rocks, once surrounded and buried by covering strata, uplifted and peneplained; and then, after another uplift, left in relief by the relatively rapid downwearing of the weaker covering strata; finally, after a recent and slight submergence of the surrounding lowlands, violently attacked by the sea and now moderately cut back from their then developed outlines. It would be convenient to have a name for small forms of this kind as well as for the larger ones.

A Tour in Brittany.—We crossed from Jersey to St. Malo in Brittany, and were there conducted by Professor Antoine Vacher, then of the University of Rennes, now of Lille, around a well chosen route, on which we saw an excellent variety of scenery. The northern uplands, submaturely dissected, had irregular sea cliffs and recently sub-

merged valleys. Cliffs of decreasing height were rare or absent. Hence, here again we found indications of a moderate measure of cliff retreat from an initial shore line produced by the transgression of the sea across a submerged lowland, until it stopped on the distinctly sloping border of an upland of more resistant rocks. Thus we felt for the third time the need of a more concise name for the total "thing" of which Brittany as well as Cornwall and Jersey was supposed to be the present phase.

A fine branching embayment of the northern coast served to locate the city of St. Brieuc, an excellent center for local excursions in this picturesque district. In view of the typical development of branching embayments, here as well as on the other side of the Channel, it is

FIG. 8.—The sloping cliffs of the uplands of northern Brittany, undercut by young sea cliffs; near St. Brieuc, looking west.

singular that their simple explanation by the submergence of previously eroded valleys was not invented on these long-known coasts; and still more singular that, sixty years after its invention by Dana to account for the irregular sea-arms which he saw in certain Pacific islands when he was geologist of the Wilkes expedition, this simple explanation was still held to be in need of elementary elucidation when presented only a few years ago to the readers of the most scientific geographical journal published in France!

Farther west a south-north valley, deeply incised in a remarkably even part of the northern upland belt, demanded the construction of one of the loftiest viaducts on the line of an east-west railroad. We crossed the viaduct in the evening and looked down from it on the lights of Morlaix deep beneath on the valley floor. The next morning we admired the great viaduct of two-storied stone arches as we drove from the town up the valley on our way southward across country.

Our route soon led us out of the valley over the even upland to its inner (southern) border, where it gradually passes into rolling hills of slowly increasing height. The transition is gradual and there is no sign of an ancient sea cliff; the transition seems to coincide with a change of rock resistance, of which the culmination was found in a long, high, narrow-crested ridge, following the east-west trend of a belt of vertical slates. Hence here, as in Cornwall, the upland was regarded as a subaerial peneplain, and not as a plain of marine denudation. The sharp-crested slate ridge is a part of the northern one of two east-westerly ribs by which the uplands of Brittany are divided into several belts. After descending from the northern rib, we crossed an intermediate upland belt near its western end; its surface there is rolling, but it is trenched by an incised meandering valley of remarkably perfect development. The river that cut this valley must have learned to meander before the beginning of the present cycle of erosion, even if the cycle in which its meanders were developed was interrupted before all the neighboring hills had been deduced to a plain.

Further progress southward took us through another rib to a southern upland. There we first turned westward to the extremity of one of the points that encloses the large bay at the western extremity of Brittany, a fine locality for the study of marine action on a dissected and partly submerged upland; then eastward to a middle part of the southern upland where it slopes to the sea and is transformed by submergence into a group of small islands, known as the Morbihan. Somewhat farther east we walked over the uplands where they are trenched by the transverse gorge of a south flowing river, the Vilaine; and afterwards following up this valley we came to a lowland excavated in an area of weak rocks within the central uplands. In this lowland lies the city of Rennes. During this delightful tour we found much confirmation of an impression that was formed during a shorter visit eleven years before; namely, that Brittany, like Devonshire-Cornwall, may be described chiefly in terms of two cycles of erosion; the first of which had reached an advanced stage when it was interrupted by the broad elevation which introduced the second; while the second reached a submature or mature stage when it suffered the slight and recent episode of depression, whereby the distal parts of the valleys were converted into little bays.

THE THING CALLED A "SKIOU."—As we were leaving Brittany we noted from the passing train, with the aid of our geological maps, how the crystalline rocks of the uplands disappear under the covering strata which dip gently eastward into the Paris basin. Our talk again returned to the "thing" for which a name was wanted, here as well as in Devonshire, and then, as if losing patience over the delay of our paraphrasing, I exclaimed; "Let us call the thing a

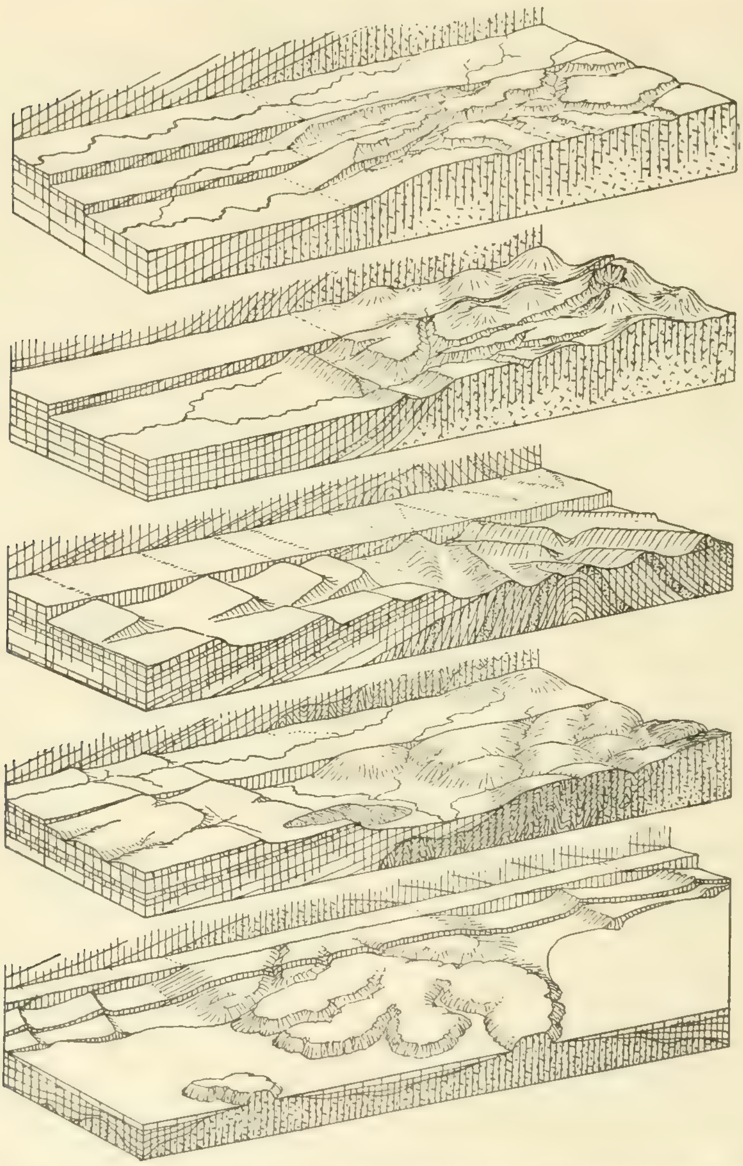

FIG. 9.—Five morvans. The first is the simplest example; its only special feature being a double uplift, resulting in two-cycle valleys in the hard-rock uplands: the angle of intersection between the two plains which truncate the hard-rock mass is small. The second has a larger angle between the two truncating surfaces of the hard-rock mass; the later surface is much interrupted by large monadnocks; and the higher valley-heads of the present cycle have been glaciated; a single monoclinal ridge rises from the lower plains near the mountain base. The third has for its older mass a body of stronger and weaker strata of folded structure, exhibiting Appalachian zigzags; while the overlying strata include four resistant members or cuesta makers, so grouped as to produce overlapping, close-set and open-spaced cuestas. The fourth has a mendip which interrupts the lowlands and indents the first cuesta. The fifth is a partly sea-girt morvan with a wholly sea-girt mendip near by.

Skiou!" Not that Skiou was a word of orthodox etymology, for it has no more ancestry than "gas," but that its adoption would cut short all vain dispute as to the rival claims of Latin and Greek roots. From that time forward, Skiou was used in our daily discussions and was recorded in our note-books. One pilgrim even went so far as to draw a series of block diagrams, representing skious of different kinds, varying with the different values of its variable elements. The word was regarded only as a provisional or slang term which might serve until something better was found, as stated below.

A VISIT TO THE LIMOUSIN.—Our next stop after Brittany was in a district of central France known as Limousin, which comprises the western part of the crystalline highlands; the eastern part where lavas become abundant being known as Auvergne. There we had the expert guidance of Albert Demangeon, then Professor of Geography at the University of Lille, now called to the University of Paris, who had the year before published an excellent article on this district. He showed it to consist of a rolling highland, sometimes smooth enough to be called a peneplain, above which rose a higher highland on which traces of a still earlier peneplain were detected, and beneath which valleys of later erosion were more or less sharply incised. An aberrant feature, west of the main body of the highlands, results from the occurrence of a body of weaker sedimentary strata, which had been faulted into the crystalline mass probably before the erosion of the higher highland, and which has now been broadly excavated to a late mature, in part to a nearly senile stage of low relief, in the same cycle of erosion as that in which the narrow valleys of the adjoining highland were incised. This lowland basin with its subdued hills is therefore one of the many illustrations of the much more rapid advance of weak structures through a cycle of erosion than of hard structures. In the lowland and because of its low relief, lies the city of Brives, the largest center of population in the district.

The crystalline highland and the weak-rock lowland are now separated by a well defined slope, nearly a thousand feet in descent, which seems to be a good example of a fault-line scarp; that is, of a scarp due to the action of erosion on a faulted mass in a later cycle than the one that was introduced by the faulting. During the earlier part of the later cycle the resistant rocks stand up while the weaker rocks are worn down, and the fault surface which separates them is thus revealed, more or less battered by weathering and notched by ravines. In the latter part of the cycle, when the highlands are worn down, then the fault-line scarp of course disappears. A fault-line scarp thus defined, should be distinguished from a fault scarp, which is initially due to displacement, and on which erosion acts from the beginning not to reveal the scarp but to obliterate it.

The unsettled question that we discussed in the Limousin turned chiefly on the number of cycles of erosion which the features of the district exhibited, and which therefore ought to be mentioned in a geographical description. Some members recognized more cycles than did others; but all were agreed that it was desirable to phrase the description of the observed features in terms of the cycles of erosion that they have suffered, however many these may be; and also in terms of the stage of development that the successive cycles had reached when they were interrupted by the displacement which introduced the next cycle.

The Volcanic District of Auvergne.—On leaving the Limousin and entering the Auvergne, we came under the enthusiastic leadership of Ph. Glangeaud, Professor of Geology of the University of Clermont-Ferrand. We ascended from a deep glacial trough eroded in the northern slope of the ancient volcano which culminates in the Puy de Sancy, and met our guide near the summit. From there, as well as from the Puy de Dôme farther east on a later day, he pointed out to us a great variety of most interesting features, among which were:—the rolling crystalline highland and the mature valleys eroded beneath it; the broad lowland plain known as the Limagne, excavated in a body of lacustrine sediments that are down-faulted next east of the crystalline highlands and separated from them by a fine fault-line scarp; young volcanoes, such as Puy Pariou with its perfect crater; dissected volcanoes, such as the Puy de Sancy and the larger Cantal to the south; young lava flows, ragged and barren, such as those which stretch from the symmetrical Puy Côme and which curiously obstruct the valley of the Sioule; or those from Pariou, which run down deep valleys in the eastern border of the highland and emerge on the lowland of the Limagne back of Clermont-Ferrand; and those which issued from a small volcano with a breached crater farther south and ran several miles down a valley to the southeast, barring a branch valley on the way and thus forming the picturesque Lac d'Aydat; more ancient lava flows, weathered and soil covered, along the side of which gorges have been eroded, so that the columnar structure of the lavas is visible; still more ancient flows now stretching evenly across the fault by which the crystalline mass is terminated and extending forward in table-mountains on an underpinning of weak lacustrine sediments which they protect from the erosion that has elsewhere swept them away; and other ancient flows now standing up in isolated mesas, often associated with volcanic necks, over the excavated plain of the Limagne, thus proving conclusively that the lacustrine sediments once rose to the level of the crystalline highlands

on the west; and finally the oldest flow of all, which caps a low mound on the crystalline highlands. It was this last feature which suggested the only new point that our visit here brought forward; namely an attempt to correlate the beginning of volcanic activity in Auvergne with the cycles of erosion recognized by Professor Demangeon in the Limousin. The lava-capped crystalline mound, surmounting by fifty or more meters the general surface of the highland, indicated that the earliest eruption in Auvergne began before the end of the cycle in which the erosion of the broad highland, common to both provinces, was completed, and hence, before the elevation of the region to its present altitude.

No district that we visited was more replete with geographic interest than this classic ground of Auvergne, where Desmarest in the eighteenth century and Scrope in the nineteenth established so many fundamental principles on which our modern studies are based. It was noticeable, however, that although Auvergne has been minutely studied by geologists, it has not yet received geographical description in accordance with modern explanatory methods.

The Morvan of Central France.—The Morvan, a northeastern extension of the central highlands where our next halt was made, was especially interesting because of its well defined limitation on the east and west by fault-line scarps. Here once more we found a structure which might be called a skiou. So well indeed did it represent the essential features of an ideal type, that since then the local name, Morvan, has been proposed as a formal substitute for the provisional name which we used during the Pilgrimage. We, therefore, now intend to describe the uplands of Devonshire-Cornwall and of Brittany, and the highlands on the central plateau of France, as morvans, writing the word with a small m, and pronouncing it for American use in our own fashion, as we do France and Paris.

The original Morvan may be described as a morvan in which the first wearing down of the crystalline foundation was advanced to senile planation, probably in part at least by the waves of an ancient sea; in which the covering strata are the marls and limestones of the Paris basin; in which the tilting of the compound mass was very slight, perhaps a few degrees only, to the northwest; in which the first truncation after tilting was well advanced even on the crystallines sometimes locally reaching planation, but more generally not having gone beyond peneplanation, and occasionally failing to obliterate subdued monadnocks, one or two hundred meters in relief; in which the next following uplift was accomplished in two phases, the first being followed by a pause long enough for the erosion of mature

valleys in the crystalline area, and the second permitting the erosion of narrower young valleys of less depth in the distal parts of the mature valleys; in which the gently inclined covering strata on the north are so little eroded that the more resistant members still stand up, even crested and about as high as the Morvan highland, yet so much eroded that the weaker basal members are broadly excavated so as to produce a wide subsequent depression, enclosed by the inface of the first cuesta on one side and by the long stripped slope of the most ancient planation of the crystalline rocks on the other. On the east and west the highland is limited by fault-line scarps, as above stated; and on the south by a broad depression excavated on an obliquely transverse belt of down-folded or faulted weaker strata. The irregular rectangle thus defined measures about fifty kilometers on a side.

Other Morvans.—The uplands of Devonshire-Cornwall might now in their turn be described, following the explanation given for them above, as a morvan of irregular outline, measuring seventy miles north and south by sixty miles east and west, with a tapering south-westward extension about fifty miles in length; normally limited on the east by a distinct but irregular slope which descends to the newer peneplain that has been worn down on the weaker covering strata; and supposed formerly to have been limited in the same way on the north, west and south; but on those sides now cliffed by the sea in consequence of a recent depression by which the presumable lowlands thereabouts have been submerged: hence this example is on three sides a sea-rimmed morvan.

The evident advantage of this style of description lies in the abundant meaning that is packed into the technical term, morvan, for if the reader already knows what the term means, a long general introductory description is cut out and the attention is at once turned to the special features which characterize the particular example under consideration. The term morvan may thus come to have in geography a value of the same kind, perhaps of the same degree, that is possessed by such a term as logarithm in mathematics. No mathematician would to-day delay his statement by presenting in paraphrase the somewhat elaborate meaning that is so conveniently packed into the single word logarithm; and so perhaps no geographer, fifty years hence, will embarrass himself and his readers by the long circumlocution that is required if morvan or some convenient term is not employed, when the thing that is meant by the term is to be considered.

If this scheme of description is followed further, one might say that the Front Range of the Rocky Mountains in Colorado is a long morvan, of which the crystalline mass was long ago worn down to

a remarkably smooth surface, and buried under a heavy series of covering strata; that the compound mass was then bent in an east-facing monoclinal flexure of great north-south extent, with a maximum dip of some thirty degrees, but that the flexure was sometimes ripped into a fault; that the truncation of the flexed mass produced a fairly good peneplain over large parts of the crystalline area, but left good-sized monadnocks standing singly or in groups; that after the later uplift the covering strata, already smoothly worn down a first time in the previous cycle, were again, because of the broad uplifting of the region, worn down to a plain of vast extent, except for a few monoclinal ridges near the mountain border; while the uplifted or up-arched peneplain of the crystalline rocks was only submaturely dissected, and in its higher valleys strongly glaciated, as has already been set forth without the use of the term morvan, in an earlier article in these Annals.

Morvans and Mendips.—Whether the island of Jersey should be described as a sea-rimmed morvan is doubtful; for so long as the inferred surrounding strata are invisible, it can not be determined whether the crystalline rocks of the island gained the height that they once possessed above the level of the upland peneplain by deformation after burial, as is implied in typical morvans, or whether the former height of the crystallines above the level of the upland peneplain was simply due to the mountainous relief of the fundamental surface before and during the deposition of the covering strata. A standard example of the latter relation in England is found in the Mendip hills, which rise through the covering strata east of Devonshire without deforming their moderate eastward dip; an equally good American example is seen in Baraboo Ridge south of the crystalline highlands of Wisconsin. The small size of the Channel Islands may be taken to indicate that they are more probably sea-girt mendips than sea-girt morvans.

The Valley of the Armançon.—A short detour was made to the northwest from the Morvan, so as to examine one of the larger consequent valleys—that of the Armançon, a member of the Seine system—by which the broadly truncated strata of the Paris basin are to-day incised. The few days spent there were profitable in discovering many details characteristic of a valley of this kind; the most notable of which are due to the occurrence of overlapping cuestas, that is, of cuestas separated by so narrow a subsequent lowland that the back slope of one cuesta descends into the mouth of each transverse valley that is eroded in the next. Another interesting detail is that the valley of the

Armançon, which often has a rather direct course, must nevertheless have been carved by a meandering river; for its course is meandering wherever the resistant cuesta-making strata descend to the level of the valley floor. There the valley is not yet widened sufficiently to destroy the meandering form that presumably existed all along its length in an earlier stage of its erosion; but wherever the lower slope of the valley sides is occupied by weak strata, they waste easily and sap any harder strata that may overlie them. Hence, in these stretches the valley has already been so much widened that all traces of its earlier meanders are lost.

The occurrence here of several successive cuestas so close together that they overlap suggests the need of selected adjectives for the description of cuestas in terms of the distance that separates them. Thus we may speak of overlapping cuestas, as in the present case; of close-set cuestas, where the back slope of one, as it descends into the floor of a longitudinal valley, just reaches the inface of the next; and open-spaced cuestas, where a broad lowland is developed between the back slope of one and the inface of the next. The controlling factors for these three cases are chiefly the thickness of the several strata in the cuesta-making series, the dip of the series, the depth of the dissection, and the stage of erosion.

The Jura Mountains.—In the Jura Mountains we were met by Dr. Fritz Nussbaum of the University of Bern and Mr. Wyss, one of his students who was engaged in a special study of that district. We spent several days under their guidance in trying to determine whether these mountains bear the marks of two cycles of erosion, separated by a broad uplift with little deformation, as is believed by Brückner and Machatschek; and if so, what stages of erosion were reached in each cycle. The occurrence of several reduced or truncated anticlines of resistant limestone led us to accept the two cycle theory, and to regard the first cycle as having reached a far advanced stage over large areas, although strong residual reliefs seem to have survived where the strongest limestone anticlines, even if much reduced in mass, rose well above the level of truncation elsewhere detected. The second cycle has already produced old forms in the synclines of weak strata, but the valleys that cut through the strong limestone anticlines are still narrow and young, with abundant rock outcrops and frequent rapids in their streams. This conclusion was reached with some regret, for the Jura Mountains, considered as a one cycle range, had a high pedagogical value. Now that they must be displaced from the elementary position in which they have been long classed, where shall we find a one-cycle mountain range of folded structure with which to

replace them? It is to be noted, however, that if the Jura mountains are to be regarded as a two-cycle range, the difficulty of accounting for the transverse watergaps or "cluses" through the hard limestone anticlines, is apparently lessened by removing the origin of the transverse streams from the little advanced current cycle to the much farther advanced preceding cycle.

Before entering the Alps we visited, under Dr. Nussbaum's guidance, the hilly piedmont district between Bern and Luzern. The forms here seen were entirely the product of normal erosion; but along the streams our leader pointed out the several terraces which are correlated with the successive glacial epochs of the neighboring Alpine valleys.

Overdeepened Valleys in the Alps.—Our traverse of the Alps from Luzern to Lake Maggiore by way of the Brünig, Grimsel, Furka and St. Gotthard passes, was a memorable experience, even though the walk over the Furka was in clouds and rain. The finest part of this trip was the two-days walk from Meiringen up the Aar valley and over the Grimsel pass to the head of the Rhone. The profound influence of glacial erosion was, to our eyes, indisputable. The heavy limestone sill across the broad trough floor, by which the basin of Innetkirchen is inclosed a short distance above Meiringen, and the narrow slit of the Aar gorge through the sill, were most impressive illustrations of what ice cannot do and what water can do; or, if the reader prefers, of what ice can do and what water can not do. Hanging lateral valleys were too abundant to count. We looked with especial care at the form of the overdeepened trough for a score of miles or more, to determine to what extent its excavation had been preceded by the normal erosion of a sharp trench in the floor of the mature preglacial valley, as suggested by de Martonne; and we were obliged to reject such trenching as an essential precursor to deep glacial erosion of main valleys below side valleys, not merely because we found no signs of it, but because the occurrence of two-storied hanging valleys, of which we saw several examples, is essentially inconsistent with it. By two-story hanging valleys, we mean lofty branch valleys which hang over middle-height side valleys, which in turn hang above overdeepened main valleys; all these valleys having the well-defined trough form that is indicative of strong glacial erosion. The occurrence of two-story hanging valleys demands strong erosive power on the part of the mid-height side glacier, independent of any gorge that may be supposed to have been trenched in the floor of the main valley in immediately preglacial time; and if we are obliged to attribute strong erosive power to medium-sized side glaciers, we

must attribute still greater erosive power to the main glacier, which therefore can have excavated its great overdeepened trough about as easily without as with the aid of a preparatory gorge of normal erosion.

It is perhaps true that, as de Martonne urges, the preparatory erosion of a normal gorge in the floor of a mature valley would facilitate the excavation of an overdeepened trough by glacial erosion; but even if so, it does not follow that this favorable condition was presented. The ancient glaciers may have had to do their work under conditions less favorable than the best. A more general objection to the idea that preglacial gorges are necessary aids to the glacial overdeepening of main valleys is found in the widespread occurrence

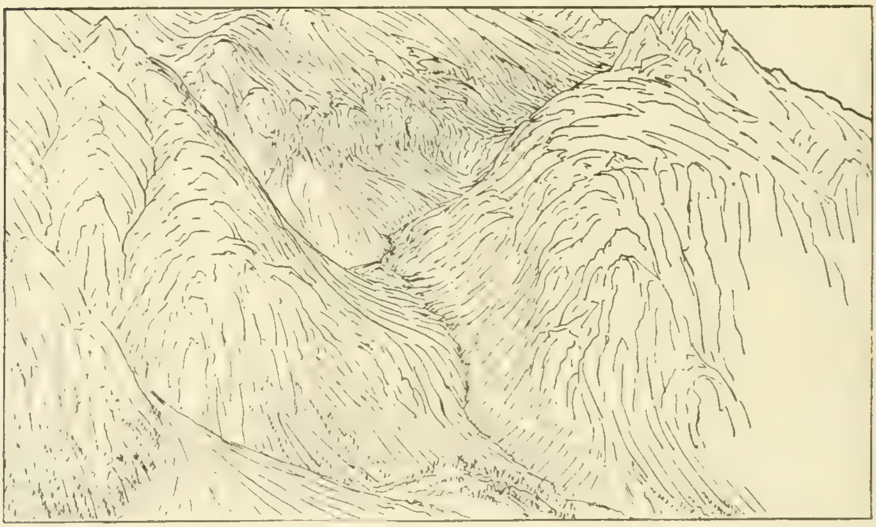

Fig. 10.—Diagram from a rough sketch of a two-story hanging valley on the west side of the Aar valley, near Handeck on the road over the Grismsel pass; looking northwest.

of mountain ranges in which the various features resulting from strong glacial erosion are easily recognized. If the production of these features by glacial erosion was dependent upon the preparatory erosion of narrow gorges in mature valleys in immediately preglacial time, we should then have to postulate a revival of normal erosion in all formerly glaciated mountains shortly before their glaciation took place. While this is not impossible, it is so special a condition that it is extremely improbable. To assume it would embarrass more than it would aid the theory of glacial erosion.

Close attention was furthermore given in the Aar valley to the occurrence of benches on the valley sides, from which successive

epochs of glacial overdeepening have been inferred by some observers. Various opinions were held on this point by different pilgrims. For my own part, while it was easy to recognize one great trough of somewhat irregular or immature form, excavated beneath the higher mountain slopes, and while it was easy to see changes of slope in many profiles of the trough walls, the benches thus indicated were too ill-defined, too irregular, and too discontinous to be accepted as proving the glacial excavation of a sucession of troughs of smaller and smaller size to greater and greater depths.

Lake Maggiore.—Our walk from Hospental over the St. Gotthard pass and thence down the valley of the Ticino, with several long lifts

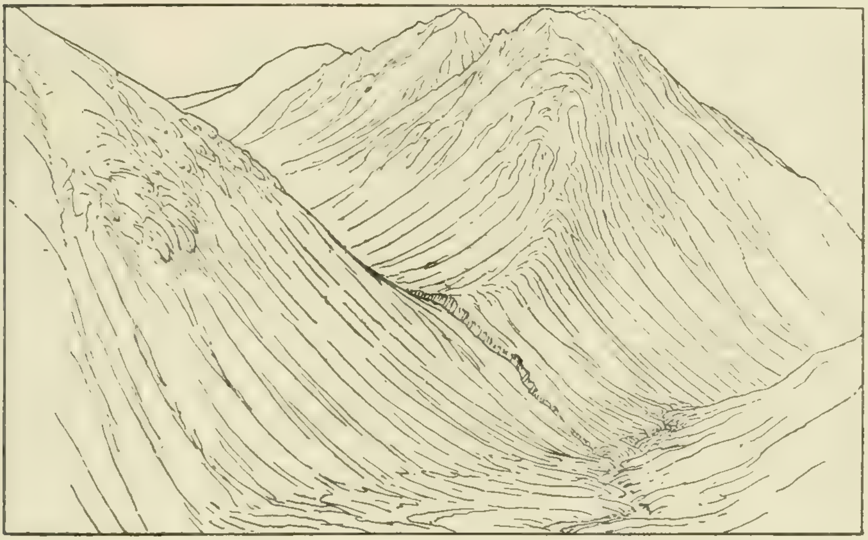

Fig. 11.—The Guspistal, a well defined hanging valley south of Hospental, as seen from road over the St. Gotthard pass; looking southeast.

by train, only confirmed the impressions gained in the valley of the Aar. The valley of the Ticino and its extension in the basin of Lake Maggiore can be confidently recommended to any observer, already familiar with mountains and valleys of normal erosion, who wishes to find conclusive evidence by which to settle the question of glacial erosion. Hanging lateral valleys abound in the mountain slopes above the lake waters, as well as farther up the Ticino. Moreover, we now have for the valley Lautensach's thesis, " Die Uebertiefung des Tessingebietes."[3] For the lake there is no detailed description which

[3] Penck's Geogr. Abhandl., Berlin, 1912.

discusses in sufficient detail the smoothness of the trough at and below the lake level, and the countless normal valleys by which the trough sides are dissected above the lake level. It was interesting to find on the Italian maps of the lake that its western arm, where a large branch glacier came down from the Simplon pass, is of much less depth than its main trough, and that there appears to be an abrupt increase of depth where one joins the other, as if the western arm were a submerged hanging valley.

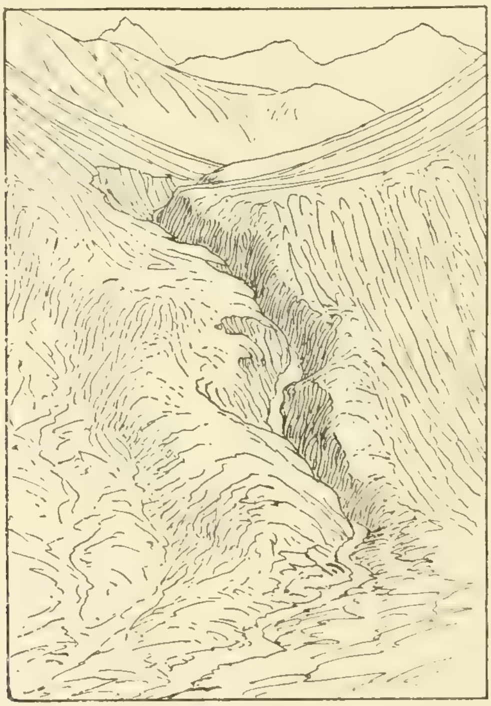

FIG. 12.—Front view of the Guspistal, showing the connecting gorge; looking east.

We were joined at the head of this beautiful lake by Professors Olinto Marinelli of Florence and Guiseppi Ricchieri of Milan, who then acted as our guides until the party broke up at Lugano a few days later. We had their pleasant company during an ascent by inclined railway of Monte Mottarone next south of the west arm of Maggiore, and during a delightful afternoon in a morainic amphitheater formed by an out-going branch of the Ticino-Maggiore glacier which excavated the small distributary basin of Lake Varese, a typical example of its kind in a densely populated and closely cultivated district of great scenic beauty. The party disbanded at Lugano.

ANNALS OF THE ASSOCIATION OF AMERICAN GEOGRAPHERS
Volume II, pp. 101-104

# MEMOIR OF CHRISTOPHER WEBBER HALL

LAWRENCE MARTIN

Professor C. W. Hall, of the University of Minnesota, a charter member of the Association of American Geographers, died at Minneapolis, May 11th, 1911, at the age of 66 years.*

He was born February 28th, 1845, at Wardsboro, Windham County, Vermont. His father, Lewis Hall, was a well-to-do farmer and his mother, Louisa Wilder Hall, was the daughter of a tanner.

Professor Hall obtained his early education in the district schools of Vermont, after which he studied in the academies at Townsend and Chester, where he prepared for college. He paid his way by teaching penmanship. He graduated from Middlebury College, Vermont, in 1871 as Bachelor of Arts and received the degree of Master of Arts from the same institution in 1874. While in college he won a botanical prize and was on the Waldo Foundation for two years. His scholarship was so excellent that he was elected to Phi Beta Kappa.

After graduating from college he was principal of Glens Falls Academy, New York, for one year. At the end of this year he moved to Minnesota, where he lived and worked the remainder of his life. He was principal of the Mankato High School, for a year, and superintendent of city schools at Owatonna, Minnesota, for two years. In 1875 he resigned in order to continue his scientific studies abroad, going to Leipzig, Germany, where he studied geology and allied subjects for two and a half years. On his return, he gave a course of lectures at Middlebury College.

In April, 1878, he was called to the University of Minnesota as instructor in geology, was made assistant professor the following year, and professor a year later. The rest of his life was given up to teaching at the University of Minnesota, and to field work, which was largely within that state. He was professor of geology, mineralogy, and biology from 1880 to 1890, and professor of geology and mineralogy from 1890 to 1911. He was head of the department of geology.

In 1892 he was made Dean of the College of Engineering, then called the College of Mining, Metallurgy and Mechanical Arts, continuing this work for five years. He did much to put the College of Engineering on an effective basis. He was also instrumental in secur-

* Many of the details concerning Professor Hall's life have been furnished by Professors F. W. Sardeson and E. M. Lehnerts of the University of Minnesota.

ing an annual appropriation for maintaining and developing the School of Mines, and in urging the appropriation of funds for the laboratory for the testing of structural materials. He secured by subscription $5,000 from the business men of Minneapolis to construct an ore-testing plant on a commercial basis. It is said by one of his colleagues that the development of the scientific technical work of the institution to its present broad and comprehensive scope has been largely due to Professor Hall's active and persistent efforts. He also foresaw the need of a School of Mines of the highest rank and earnestly recommended its establishment in order to meet the demands upon the state university, created by the discovery and operation of the rich iron mines and the clay and quarry industries in Minnesota.

During his first years at the University of Minnesota, Professor Hall was assistant geologist on the Geological and Natural History Survey of the state, and from 1883 to the time of his death he was assistant geologist of the United States Geological Survey. During his many summers of field work he traversed nearly every portion of the state of Minnesota, going over many of the counties in great detail. Within this period, and during a year's leave of absence in Europe in 1897-1898, he did much to familiarize himself with the physical features of the land and their relationships to human affairs. In the winter of 1908-9 Professor Hall went to South America where he attended the Pan-American Congress at Santiago.

Besides being a member of our own Association, Professor Hall was a fellow of the Geological Society of America; a fellow of the American Association for the Advancement of Science; a member of the National Geographic Society; a member of the Minnesota Geographical Society; a member of the Society for the Promotion of Engineering Education, and of the Minnesota Academy of Natural Sciences. For many years he was editor of the Transactions of the Minnesota Academy. He was secretary and administrative officer of that society for 14 years, and its president in 1900 and 1905. In 1910 he was vice-president of the American Association for the Advancement of Science, presiding over the meetings of Section E., Geology, and Geography, at the Minneapolis meeting.

While Professor Hall was interested in geography throughout his career, he fostered its development chiefly in his later years, both by teaching in the University, and in his own field work. He was one of the rapidly-diminishing number of American geologists who was trained in and connected with all of the branches of the subject, so that while his geographic work did not attain to the degree of specialization which is possible where one is not teaching and working in general geology, mineralogy, petrography, historical geology, structural geology, water resources, etc., as well as geography, the broad-

ness of view of the relationships of geography to the larger subject of geology was well maintained.

The modern trend toward specialization is shown, however, in Professor Hall's life. He started as a naturalist, of the good, old-fashioned type which is now all but gone. From 1878 to 1884 he taught all the natural and physical science at the University of Minnesota, with the exception of chemistry. Later he taught nothing but geology and mineralogy, but he was a man of sufficient all-round training so that he was able to make an efficient dean of the College of Engineering. Still later he had specialized sufficiently in geology so that he treated technically, in teaching and investigation, various subjects in geology, and his tendency toward geography is shown by three lines of activity.

His special geographic interest is evidenced, first, by the courses that he gave at the University of Minnesota, where he introduced geography as a subject of instruction. He seems to have first taught the subject there about 1900. His course on The Geography and Geology of Minnesota dealt, in his own words, with "the physical geography of the state in its relations to geological history and industrial development." This course he retained to the time of his death. A little later he introduced a course in Physiography, giving also to this course the fundamental relationship to human affairs that characterized his treatment of the geography of the state. The physical geography course treated, as Professor Hall said, "the principles of earth sculpture with special reference to ethnic movements and commercial activities of man."

His publications contained many geographical and educational topics, including a syllabus of physical geography and a book on The Geography and Geology of Minnesota. This book, published in 1903, fully attains the aim of the author, as stated in the preface, of a work "not written in the style usual in the textbooks of the schools. It is prepared rather to read." Hall's Geography of Minnesota is eminently readable. Comprehensive, authoritative, simple, — this little monograph on state geography is interesting. In writing it, he stated in his modest style, what the book amply accomplished, that "if interest be aroused and attention directed in a plain scientific way to the wealth of geographic illustration Minnesota affords, the object of the author is realized."

The third outward and visible sign of Professor Hall's geographic labor — his affiliation with co-workers in geography, is known to members of this Association who have welcomed him in his occasional attendance at our meetings. At the 1906 meeting in New York he gave a paper on "A Climatological Cause of the Prairies." The following year, at the Chicago meeting, he gave a paper on "The Conservation

of the Upper Mississippi River." Less familiar to us is the way he fostered geography in his own community by organizing the Minnesota Geographical Society, of which he was the first president.

His personality was attractive, objective, virile. Coming from sturdy Vermont stock he undoubtedly added strength to the community in which he dwelt and worked, in the Northwest. He pioneered in Minnesota when the country still partook somewhat of the frontier character. Doubtless his geographical appreciation was aided by the clearness of geographical relationships always to be seen in a region growing from the borderland stages to the settled conditions by which Professor Hall was surrounded in the later years of his life. The state in which he lived, however, still retains, in its unsettled northern wildness, the crude and obvious frontier relationships of geography to man.

A man of less vigorous personality would have seen and made use of much less in the geography of Minnesota than this lately-departed friend of ours, who combined much that was best of Vermont and Minnesota, of broad naturalist and technical geographer.

Professor Hall was in politics a broad-gauged Republican, but he never sought nor held office. He was twice married, in 1875 to Ellen A. Dunnell, who lived only seven months after their marriage, and again in 1883 to Sophia Seely Haight, who died in 1891, leaving one daughter. His physical activity and strong method of verbal and written presentation made him a forceful personality, to whom many students and friends in the Middle West owe much for the development of a geographical point of view, and with whom the members of the Association of American Geographers may well join in expressing their regret at his loss.

In conclusion, let me quote his own words regarding our subject. They reflect much of the spirit and style of the man. He says geography is "a new field for obtaining intellectual satisfaction. It gives redoubled relish to travel, furnishes crumbs of comfort to those who remain at home and becomes the formula for solving economic and social problems. The causes of geographic forms arouse inquiry; their cycle of development can be followed and the maturing conditions of each stage become better understood. It is then appreciated that land forms have a history as well as the institutions which are founded upon them. Given this appreciation, and such a study of geography as shall make clear the causes of events and associate them with those geographic conditions that establish the relations of earth and man, and the study becomes scientific; Geography is a Science."

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Volume II, pp. 105-118

# TITLES AND ABSTRACTS OF PAPERS

Washington, 1911

Presidential Address—Ralph S. Tarr.

The Glaciers and Glaciation of Alaska.—Printed in full herewith.

Lawrence Martin.

Memorial of Christopher Webber Hall.—Printed in full herewith.

N. M. Fenneman.

A Classification of Natural Resources for the Use of Conservationists.

One reason for a confusion and sometimes a doubt in the public mind with reference to conservation policies, is the failure to classify natural resources and limit statements to the class for which they are intended. The scheme here suggested provides four classes:

Class A — Natural forces and stores of materials which are not only inexhaustible, but practically unlimited.

Class B — Forces and stores not subject to exhaustion, but strictly limited in quantity.

Class C — Exhaustible stores which are reproduced at slow but perceptible rates.

Class D — Exhaustible stores which can not be replenished.

Much of the hope of the human race lies in Class A. Illustrate by the successful appropriation of atmospheric nitrogen; supply of clays, cement materials, etc.; possible direct use of sun's rays. Class B is illustrated by the land (soil) and by water power, permanent in their nature, rising in value and capable of being monopolized. In this class lies the chief danger to republican institutions. Of Class C (forests, useful wild animals like the elephant, etc.) the annual crop only must be used (as will be done with forests) or the kind exterminated (as may be done with elephants). Resources of Class D (illustrated by coal, most metals and some fertilizers) will be exhausted. The period of their exploitation will be a brief epoch in the history of the race. Conservation should retard the process of exhaustion in order to reduce as much as possible the hardships of transition to the new order.

Richard E. Dodge.

Geography and Human Construction.

Illustrations were given of results from building or construction

to meet average rather than extreme physical conditions, as seen in sewers too small to carry off excessive rainfall, in water and gas pipes not laid below extreme frost depth, walls and dams not built to meet extreme soil or water pressures, and similar instances.

Mark Jefferson.

Houses and House Materials in West Europe.

The house, especially of the poor man, is made of the materials nearest at hand: if among abundant forests, of wood; where the forest is lacking, of stone or brick. Roofs are especially sensitive to the influence of local building materials, from their exposure to the weather and consequent frequent need of repairs. Where some fissile rock abounds, they are of slate-like slabs; where the rock is clayey, of tiles; in the forest, of shingles; the poorest house often having thatch in any country where neither shingles nor slates are to be had.

Inheritance, however, is also to be reckoned with.

J. Walter Fewkes.

The People of the Junipers: A Study in Human Geography.—Read by Title.

R. H. Whitbeck.

Industries of Wisconsin and Their Geographic Basis.—Printed in full herewith.

C. F. Marbut.

The Relation of the Glacial Lake Deposits of Central New York to Soil Mapping.

The author called attention to the recent work of the Bureau of Soils in Monroe and Ontario Counties, New York, and invited discussion and criticism of the work as well as of the system of soil classification adopted for the region.

H. H. Bennett (Introduced by C. F. Marbut).

The "Flatwoods" of the Coastal Plain and Its Soils.—Presented in Abstract.

The author defined the term "Flatwoods" and described its general physiography. Its soils were discussed with reference to their physiographic relations illustrated by the soil maps of Georgetown County, South Carolina, and Glynn County, Georgia. The relation of soils and physiography to population was discussed, with especial reference to the agriculture of the region.

C. F. Marbut.

The Geography of the Ozark Dome and the Boston Mountain Plateau in Missouri and Arkansas.

The author undertook to show the relations to each other of the various members of the Ozark highland system and compared the region as a whole with the Appalachian region. The physiography and general character of the soils were described and the relation of these two factors to the history and present condition of the population of the region was discussed.

Mark Jefferson.

The Anthropography of North America.

The Map.—Interpretation of the map.—The point of view geographic, i. e., that there is a human response to environment which may be made out on such a map, the grades of density, their selection and history. The U. S. Census grades, influence of the point of view, treatment of cities, treatment of forests, isanthropic lines, the data and their treatment.

Henry C. Cowles.

An International Phytogeographic Excursion.—Read by Title.

In August, 1911, there was initiated in England a type of excursion that is likely to be repeated in other countries. The British phytogeographers had invited guests from various countries to spend a month with them in studying together selected areas of phytogeographic interest. The results of this excursion are likely to prove of inestimable value.

Alexander G. Ruthven.

The Local Distribution of the Reptile-Amphibian Fauna in Southern Vera Cruz and Its Bearing on the Origin of the Savannahs.—Printed in full herewith.

Stephen A. Forbes (Introduced by R. S. Tarr).

Some Features of the Geographical Distribution of Illinois Fishes.

As one of the products of a long series of collections of Illinois fishes, extending over about thirty years, a set of maps of the state was prepared showing the Illinois distribution of each species. In searching for the cause of the peculiar limitation of the distribution of a considerable number of fishes, it was found that the area apparently avoided by them was that of the lower Illinoisan glaciation. The waters of this glaciation are very remarkable for their persistent turbidity, due to an extremely fine division of the soil such that the water can not be rendered clear by repeated filtration with the finest filtering papers. These soils are also slightly acid, and their particles are consequently not aggregated into so-called granules, but remain mechanically separate.

On a comparison of the situations in which the fishes of the above

mentioned group are generally found with the situations in which other Illinois species occur, it appeared that they are characterized, as a group, by their avoidance of muddy waters, from which it was inferred that the persistent turbidity of the waters of the lower Illinoisan glaciation was the cause of the scarcity of the fishes of this group in that environment. As the collections were originally made without reference to this hypothesis, which was framed as a result of their study, it was thought best to test them by additional collections made over the same area. This was done during the summer of 1911, with the result that the distribution maps of the species of this particular list were scarcely changed by the collections made within and without the area of the lower Illinoisan glaciation.

From the foregoing it may be inferred that the local distribution of Illinois fishes has been considerably influenced by the geological history of the lower Illinois glaciation.

W. M. Davis.

A Geographical Pilgrimage from Ireland to Italy.—Printed in full herewith.

W. M. Davis.

The Trans-Continental Excursion of the American Geographical Society in 1912.

H. L. Bridgman.

Exploration. Its Conditions and Rewards.—Read by Title.

Isaiah Bowman.

The Geographical Results of the Yale Peruvian Expedition.—Read by Title.

The paper presented a description of geographic work and results, the physiography of the Andine Cordillera from the mouth of the Timpia to Camaná, human relationships, a series of new topographic maps illustrating the chief physiographic problems, temperature curves and notes on climate, the problem of the *andenes* or artificial terraces, etc.

Sumner W. Cushing (Introduced by R. S. Tarr).

The East Coast of India—Some of Its Geographic Factors.

There extends along the east coast of India, from Cape Comorin to near Calcutta and from the Bay of Bengal some sixty miles inland, a strip of country that is made up successively from west to east of an elevated peneplain of highly distorted rocks that is nearing maturity, a plain of marine denudation from which rise many outliers, a mature coastal plain the soil of which is thoroughly "lateritized," and a young coastal plain the continuity of which is interrupted by numerous large deltas. These land forms present conspicu-

ously different environments and their occupants yield correspondingly different responses.

Philip S. Smith.
The Noatak River, Alaska.—Printed in full herewith.

Roland M. Harper.
The Relation of Geography to Certain other Branches of Learning.

The subjects considered were geology, physiography, hydrography, climatology, botany, zoölogy, anthropology, ethnology, sociology, economics, biography, history, pedagogy, cartography, and a few others which are of less importance or subordinate to those already named. An outline classification of the geographical phases of the related sciences was included.

R. H. Whitbeck.
An Estimate of Miss Semple's *Influences of Geographic Environment.*

W. L. G. Joerg.
On the Proper Map for Determining the Location of Earthquakes.—Printed in full herewith.

R. H. Sargent (Introduced by Alfred H. Brooks).
The Principles and Methods Employed in Making Topographic Maps.

This paper outlined the principles and methods employed in the construction of the topographic maps of the U. S. Geological Survey. While the principles in all topographic surveys are the same, the methods of applying these principles differ widely, being governed by the purposes of the survey and the conditions under which they are made.

The preparation of topographic maps may be divided into three stages:

(1) The field surveys, which are essentially by plane-table method.
(2) The assembling of the field data.
(3) The engraving, proof-reading, and printing.

F. E. Matthes.
The Map of the Yosemite Valley: An Analysis.

This map is unusually instructive in that it suggests certain fundamental principles of topographic delineation not generally observed by map makers. It portrays a multitude of relief forms of a somewhat unusual category, namely, details of cliff sculpture produced by erosion in rocks of aberrant structural habit. These features, it so happens, are of great importance in the Yosemite landscape—it

is in them that the principal chapter of the Yosemite Valley is to be read. Fortunately, the scale and contour interval selected were adequate for their detailed representation; also, the delineation was executed with consistency throughout, all features of the same order of importance being shown with equal distinctness and exactness. As a consequence, the Yosemite map has turned out to be invaluable as an adjunct in the study of the Yosemite problem—indeed, but for this map that problem might be as far from solution today as ever. It tells a story—the story of cliff sculpture guided by rock structure—and tells it with clearness. Had the scale been smaller or the interval larger, the map would have cost less, no doubt, but would have failed to tell the story and its value to the physiographer would have been insignificant. Had the map been made on a larger scale and with a smaller interval, the cost would have been greater, but the story would not have been added to one jot.

The lesson to be drawn from the case is that for every landscape there is a certain scale which, with an appropriate contour interval, and at the hands of a competent delineator, yields to the physiographer the maximum value obtainable. Whether the inquiry be minute and detailed in character or synthetic and of broad scope, in each case there is a scale of maximum efficiency and therefore maximum economy dictated by the size of the topographic units involved. The success of the Yosemite map suggests the application of this principle to other maps.

Ralph S. Tarr.

The "Atlas Photographique des Formes du Relief Terrestre."

G. W. Littlehales.

The Exploration of the West Indian Seas in the Approaches to the Panama Canal as a Resource in Oceanography.—Read by Title.

The key to the advancement of the science of oceanography is to be found in the western part of the Atlantic Ocean, and especially in the West Indian Seas. Relations partly of a primary and partly of a secondary nature have been revealed, in the movements of these waters and in their properties of temperature, density, and salinity, which make it appear that the laws of the fluctuations of the Atlantic currents in regard to strength and temperature are to be looked for here. A study of the causes of these changes can be made of great economic and industrial importance because the accessions to our knowledge thus gained will furnish fresh means with which we can both diminish the adverse influence exercised upon transportation by the agencies of the sea, and also foresee those effects which are reflected in the weather and industries on land on account of oceanic changes.

W. J. McGee.

The Relation between Ground Water and Streams.

The chief source of normal streams is ground water entering the channels by seepage—in fact the normal water level in streams marks the coincidence between "the base level of erosion" as defined by Powell, and "the ground level of water" as recently defined by the author ("Soil Erosion," Bureau of Soils Bulletin 71, 1911, p. 28). Accordingly, not only the regimen of normal streams but their volume and abundance are affected by the quantity and movement of the ground water. It is estimated that in the humid portion of the country the volume within the first hundred feet is equivalent to a reservoir twenty-five feet in average depth or to six or seven years' rainfall, and that the ground water of the entire country within a hundred feet from the surface may roughly be estimated at 50,000,000,000 acre feet. Since settlement of the country (largely by reason of clearing and cultivation), the ground water has suffered a depletion marked by falling of springs, disappearance of small streams, and the decreased volume or increased fluctuation in larger streams. Recently, an attempt to determine the volume and the rate of depletion of the ground water reservoir has been undertaken by means of a well census extending into nearly every county in the United States. In nine states the lowering of ground water during a mean period of about twenty-two years has been found to average 1.315 feet per decade, or with moderate allowance for new wells, 1.73, equivalent to 13.8 during the eighty years since settlement. The rates of lowering vary from state to state in such manner as to indicate that the subterranean reservoir moves slowly down slopes, generally (though not always) in directions corresponding with the surface flow; also, that in Missouri the ground water level is partly maintained by underflow from the Plains and mountains further westward; that in Ohio the level is maintained partly by seepage from Lake Erie and that in Kentucky and Tennessee the underflow from the Appalachians helps to maintain the ground water level in the low-lying section.

N. H. Darton.

The Buried Valley of Susquehanna River, Luzerne County, Pa.

In investigating certain economic problems in the northern anthracite coal field, the writer obtained records of a large number of bore holes through the valley filling of the Susquehanna River in Luzerne County, Pa. These holes have afforded data for preparation of a new map showing the configuration of the rock floor of the old valley now filled with from 50 to 309 feet of sand, gravel, and clay. The valley bottom consists of elongated basins and irregular ridges which probably were shaped in the Glacial Epoch, but the conditions under which they were eroded are enigmatical.

Collier Cobb.

The Hanging Valleys of Alabama.

Frank B. Taylor.

The Early Part of Niagara History.

R. S. Tarr and Lawrence Martin.

An Effort to Control a Glacial Stream.—Printed in full herewith.

Douglas Wilson Johnson.

Beach Ridges of Northern and Southern Sweden.—Read by Title.

There is a well established belief in the progressive elevation of the Baltic Coast of northern Sweden during historic time, while many believe that southern Sweden has at the same time been gradually subsiding. A study of the beach ridges of the northern coast shows that there is a progressive increase in altitude of the ridges as one goes inland from the present shoreline; a fact which indicates progressive elevation without proving its recency. The character of the vegetation near the water's edge suggests recent uplift of the coast, but the ages of trees not far above water level show that the rate of uplift can not have been so rapid as is generally assumed. In southern Sweden the beach ridges indicate long continued coastal stability. The form of the ridges, and the position of ruins of ancient mounds, dwellings, and castles which are found upon some of them, prove there can have been no marked subsidence of the land in this region for several thousand years at least.

Douglas Wilson Johnson.

The Border of the Wash and the Norfolk Broads, England.—Read by Title.

The fenlands surrounding the Wash, and the marshes included in the district of the Norfolk Broads, have experienced remarkable changes in character within historic times, partly due to man's power to alter his environment, and partly to favorable changes effected by the forces of nature. Some of the changes were described, especial emphasis being laid upon those which had already produced, or which might in the future produce, a fictitious appearance of coastal elevation or coastal subsidence.

Robert Anderson (Introduced by Cleveland Abbe).

Geographic Features of Trinidad.

This paper gave a brief account of the more important geographic features of Trinidad, with special reference to the relation of surface features to the geology, and the relation of the island as a whole to the Windward Islands and the South American continent.

A. Lawrence Rotch.

Fog Formation.

Fog is an important climatic factor in regulating the temperature

and moisture over the land, but contributes danger to locomotion and navigation. Its distribution, therefore, has been plotted by climatologists and some attempts made to predict its occurrence. The various methods of formation are little understood and no distinction is usually made between fog and cloud which covers hills or mountains.

A study of the cause of fog, especially along the Atlantic and Pacific Coasts, is in progress by Mr. E. P. Linsley, formerly assistant at the University of California, but now a graduate student at Harvard University, under the direction of the author. Special observations with kites may be made at Blue Hill Observatory where there are continuous observations of temperature at stations differing in height by 600 feet. The great focus of fog is on the Banks of Newfoundland and, soundings in and above the fog-sheet with self-recording instruments carried by kites, which could be flown in either calm or windy weather from a steamer whose course could be controlled, would do much to explain its formation there. This investigation could most easily be undertaken with the aid of the U. S. Hydrographic Office with which the author made a proposition to cooperate, several years ago.

R. De C. Ward.

The Value of Non-Instrumental Weather Observations.

It is a mistake to suppose that meteorological observations made without instruments are valueless. There is a very considerable number of such observations which can be undertaken by any intelligent person, even when traveling, and which will add greatly to the interest of the journey, as well as often contribute not a little to one's knowledge of the climatic conditions of the region. The *Journals of the Lewis and Clark Expedition* afford an excellent illustration of the value of non-instrumental weather observations made in a region previously climatically unknown. Anyone who reads these *Journals* carefully will inevitably gain a remarkably clear idea of the essential climatic characteristics of those portions of the United States through which the Expedition passed on its famous journey.

R. De C. Ward.

The Meteorological Interest of the Voyage to Brazil.

To the meteorologist, the voyage to and from Rio de Janeiro is of great interest. It gives a cross-section from the prevailing westerlies of the Northern Hemisphere, across the horse latitude belt, the northeast trades, the equatorial calms and rains, and the southeast trades, ending at about the southern margin of the latter. To anyone who knows these wind and calm belts only from the descriptions printed in books, such a voyage gives an insight into the actual conditions of wind and weather which no amount of reading can supply. The "field work" which can be done on such a trip by the student of meteorology is well worth the expense and the time which the two voyages neces-

sitate. The writer made the trip to Rio de Janeiro three times, and came back from Rio to New York twice, and each time found increased interest and inspiration in it.

Cleveland Abbe.

The Atmosphere as an Integral Part of the Earth.—Read by Title.

Geology recognizes the fact that the earth, in passing from its original inchoate condition over into its present complex organization, has for ages been passing through a condition in which the rain and dusty winds of the atmosphere have been continually destroying and rearranging the slow formation of the more solid portions of the earth's surface. Little by little, wherever the solid ground appeared above the waters of the earth, there the rain and the wind and the waves of the ocean began to dissolve, break up, and wash away the exposed solid material. Thus the atmosphere has been the fundamental active cause of these perpetual changes on the face of the earth. The rate of these changes and their laws must depend entirely on the rate at which the atmosphere can assist the earth to lose its heat by radiation through the air and from the air. The solid and liquid parts of the earth can only lose directly by radiation through the atmosphere. In these steps, convection is but a temporary, slow process and eventually nearly all heat must be lost by radiation from the outer surfaces of the successive layers of gases of the atmosphere. The general cooling of the earth depends not so much on the radiation from the earth's surface as on the special selective radiations of the layers of atmospheric gases and vapors. The study of these special selective powers of radiation by the respective atmospheric gases and vapors, is therefore the true basis of all knowledge or theory as to the past evolution of our globe. The history of geological ages and the evolution of life on the globe has to do with the cooling down from 100° C. to 20° C. and with the numerous attending changes of orography during this relatively short interval. The author gave numerous examples and theories.

Robert M. Brown.

A Discussion of the Humidity Factor in Ventilation.

Sanitarians are almost unanimously agreed that in the ventilation of an ordinary room, under the common conditions of occupancy, the percentage of carbon dioxide and the expiratory breath play an almost negligible part. Sanitarians quite universally believe that the physical properties of the air must be regulated to insure the best health and, indirectly, the highest efficiency of the occupants.

With this proposition as a basal statement, the author presented a study of the problems of the physical features of the air; temperature, humidity, air motion, and electrical potential. The result of an investigation of the conclusions reached by cotton manufacturers in England

and in this country, was offered. Following, the discussion turned to the results of the study of room ventilation, with special emphasis on the humidity factor.

A large amount of experimentation is necessary. The knowledge so far gained is not so sure nor so definite as to justify the outlay for humidification plants, which are not prohibitive to-day because of expense, in our buildings. The need of further investigation along certain lines suggested is imperative.

Ellsworth Huntington.

The Big Trees of California as Recorders of Climatic Changes.

During the spring and summer of 1910, the writer studied the physiography and archaeology of Arizona and neighboring regions, for the purpose of coming to some conclusions as to ancient climatic conditions. He found strong evidences of changes of climate similar to those of Asia. Inasmuch as there was danger of being influenced by preconceived opinions, it seemed necessary to discover some new method of measuring the climate of past times. Such a method was suggested by the work of Professor A. E. Douglass of the University of Arizona. By measuring the thickness of the annual rings of some of the older trees in Arizona, Professor Douglass constructed a curve which shows the minor climatic fluctuations. Larger fluctuations were marked by the differences between the rate of growth of the trees in youth, maturity, and old age. The present writer has adopted this method. As a part of his work for the Carnegie Institution in 1911, he measured the rings of some two hundred Big Trees (*Sequoia gigantea*) of California, varying from 250 to 3,150 years of age. By making corrections for the varying rate of growth at different periods from youth to old age, he has been able to construct a curve which shows the departure of the climate at any given time from the mean. A comparison of this curve with the curve for Asia shown in "Palestine and Its Transformation" confirms many of the author's previous conclusions.

Charles Julius Kullmer (Introduced by Ellsworth Huntington).

Storm Frequency and Civilization. The Shift of the Storm Track.

A striking agreement is shown between the distribution of higher civilization and areas of high frequency of barometric depressions, and the hypothesis is advanced that storm frequency may be a factor in determining man's energy and intellectual activity. In order to ascertain whether the storm track is subject to a general shift, the maps of storm frequency in the United States were made for 1899-1908 and compared with Dunwoody's maps for 1878-87. A westward and southern shift of the storm track was shown.

Ellsworth Huntington.

The Effect of Barometric Variations upon Mental Activity.

In order to test the effect of changes of weather upon mental activity, curves have been plotted showing the variations in speed and accuracy of three persons as measured by daily tests on the typewriter for a year. These curves seem to show the existence of an intimate relationship of some sort between the fluctuation of the barometer and changes in mental ability.

Oliver L. Fassig.

Hurricanes of the West Indies and Other Tropical Cyclones.

The paper presented an analysis of the points of origin, the paths, the rate of movement, and the distribution through the season, of 135 storms of hurricane force occurring in the West Indies, as recorded by the U. S. Weather Bureau from 1876 to 1910, and a comparative study of West Indian hurricanes, Bay of Bengal cyclones, and typhoons of the Pacific.

There is a well marked path of greatest hurricane frequency through the northern half of the Caribbean Sea, extending almost due east-west from the Windward Islands to Jamaica; taking a northwest course through the Yucatan Channel, across the western end of Cuba, the path recurves in the eastern portion of the Gulf of Mexico, and crosses Florida Peninsula into the North Atlantic with a northeast trend.

There is a secondary path not so well defined, extending from the northern group of the Windward Islands in a west-northwest direction across the Bahama Islands and recurving east of Florida in the North Atlantic Ocean. Between these two paths lie the Greater Antilles—Cuba, Jamaica, Haiti and Porto Rico. Of these Islands Porto Rico and Haiti are comparatively free from the devastating winds near the hurricane centers; the western half of Cuba is crossed in the recurve of a large percentage of the storms of the Caribbean Sea, or of the main path. These two paths coincide very closely with the two branches of the great equatorial current of the North Atlantic.

The normal track for the entire season, as determined from 135 storm paths, resembles a parabola. The first branch extends in a direction west by north, between the parallels of 18° and 20° north latitude to the center of the hurricane area (20° N. and 73° W.), then northwestward and north; recurving over central Florida, the trend is northeastward over the North Atlantic, along the second branch of the parabolic path.

The path pursued depends to a great extent upon the point of origin. Those originating far to the east, as in August and September, are most likely to move west-northwest for a considerable distance along the first branch before recurving. Those having their origin in the western waters of the Caribbean Sea, like most of the storms early

in the season and those of October, move northwest or north along the recurve of the normal track, or they may, in the higher latitudes, have their origin in the second branch of the normal track. A hurricane may have its origin in any portion of the normal track, but for the balance of its existence it will follow approximately the normal path for the month in which it occurred. Of 134 storms: 63 per cent were formed in the first branch of the normal track, 17 per cent in the recurve, and 20 per cent in the second branch.

Hurricane frequency in 35 years:

| | May. | June. | July. | Aug. | Sept. | Oct. | Nov. | Season. |
|---|---|---|---|---|---|---|---|---|
| Frequency ...... | 1 | 8 | 5 | 33 | 43 | 42 | 2 | 134 |
| Percentage ..... | 1 | 6 | 4 | 25 | 32 | 31 | 1 | 100 |

Tropical storms move more slowly than those of the middle latitudes. The mean daily movement is about 300 miles, or 12.5 miles per hour.

| | In first branch. | | | | | In recurve. | In second branch. | |
|---|---|---|---|---|---|---|---|---|
| Mean velocity of | 1st | 2nd | 3rd | 4th | 5th day | Mean of 3 days | 1st | 2nd day |
| 136 storms..... | 286 | 254 | 219 | 266 | 276 | 260 | 384 | 400 |
| Means.................. | 260 | | | | | | 390 | |

The average duration of a hurricane in the first branch is from 3 to 4 days, according to the month of occurrence, and in the recurve about 2 days.

### Duration of Hurricanes.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Duration of storm, in days ................ | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Number of storms in the first branch...... | 15 | 21 | 16 | 7 | 7 | 13 | 4 | 1 | 1 |
| Number of storms in the recurve.......... | 26 | 46 | 15 | 5 | 3 | 2 | — | — | — |

### Areas within which Tropical Cyclones Originate.

| | Latitude | Longitnde. | Mean annual frequency |
|---|---|---|---|
| Hurricanes (West Indies) ................. | 12°–28°N. | 55°– 95°W. | 4 |
| Cyclones (Bay of Bengal) .................. | 8°–22°N. | 100°– 80°E. | 9 |
| Typhoons (North Pacific) .................. | 5°–20°N. | 150°–115°E. | 20 |

Conditions favoring the formation of cyclonic systems in the tropics are produced by the changes in the position and intensity of the so-called permanent areas of high and low atmospheric pressure accompanying seasonal changes and variations in the intensity of solar radiation. These cyclonic systems, once formed, are carried along in the general drift of the atmosphere—from east to west below latitude of about 30° N., and from west to east in higher latitudes.

Collier Cobb.

Changes of Level Along the North Carolina Coast.

The larger estuaries like Albemarle and Currituck Sounds, Pamlico River, and Neuse River below the point where it is joined by the Trent, all present the appearance of drowned valleys. This, however, is probably caused in some measure by a rise of the water-level consequent upon the closing of a number of inlets north of Ocracoke Inlet, par-

ticularly along Currituck Sound and in the neighborhood of Nag's Head, where a remnant of a former outlet remains in the Fresh Ponds. In fact, Albemarle Sound was called Carolina River and the Great River, by early explorers, and is so mentioned in the *Colonial Records*. The borders of Albemarle and Currituck Sounds have been somewhat extended by the cutting action of the waves, and through this action, trees have been gradually let down within a decade. "Sea Cliffs" presenting the appearance of recent uplift are invariably opposite inlets that have been closed since the settlement of the country by the English, and a number of them within the last century.

F. V. Emerson.
Some Geographic Responses in Central Kansas.

The rainfall of the area described verges on the sub-humid type. The influences of this climate upon soils, crops, and human activities was discussed.

G. C. Curtis (Introduced by A. P. Brigham).
Observations on South Newfoundland Fiords.

G. C. Curtis.
Earth Sculpture.

## ASSOCIATION OF AMERICAN GEOGRAPHERS.

### Constitution and By-Laws

I. Name and Object.

The name of this organization shall be the Association of American Geographers. Its object shall be the cultivation of the scientific study of geography in all its branches, especially by promoting acquaintance, intercourse and discussion among its members, by encouraging and aiding geographical exploration and research, by assisting the publication of geographical essays, by developing better conditions for the study of geography in schools, colleges and universities, and by co-operating with other societies in the development of an intelligent interest in geography among the people of North America.

II. Officers.

The officers of the Association shall be a President, two Vice-Presidents, a Secretary, a Treasurer (one person may be both Secretary and Treasurer), and three Councillors. These officers shall constitute a Council which shall manage the affairs of the Association. Nominations of officers, made by a committee of three members previously appointed for that purpose, must be sent to members not less than sixty days before the annual meeting of the Association. Any five members may make independent nominations which if received by the Secretary thirty-five days before the annual meeting, must be sent to all members not less than thirty days before the meeting.

The election of officers must be made by ballot at the annual meeting. Each member may make such changes as he wishes in the ballot received from the Secretary. He should then enclose the ballot in a sealed envelope, sign his name on the outside, and send or give it to the Secretary in time for it to be counted at the annual meeting.

III. Membership.

Membership shall be limited to persons who have done original work in some branch of geography. A nomination for membership must be made on an official blank, prepared by the Council, signed by two members of the Association, and sent to the Secretary. The Council shall consider all nominations; if its action is favorable, the nominee will be recommended to the Association for election; if unfavorable, the nomination will not be brought before the Association, except on the written request of both signers of the nomination and with a statement of the Council's action. All elections to membership must be by ballot, at such times as the Council may determine. Members shall pay an annual fee of $5.00; but the Council may remit this fee *sub-silencio*. The names of members two years in arrears shall be stricken from the list of the Association.

IV. Meetings.

The annual meeting of the Association shall be held within a week of January 1, but the Council may arrange other meetings in place of, or in addition to this annual meeting. Announcement of the time and place of all meetings must be mailed to members at least thirty days in advance.

V. Changes in Constitution or By-Laws may be made in two ways:

First, at any regular meeting by an affirmative vote of a majority of all the members of the Association, provided that printed notice of the proposed changes be mailed to all members with the call of the meeting, and voting shall be by ballot mailed or handed to the Secretary; second, by ballot at any time, provided that thirty days' notice has been sent to all members and that the proposed amendment has been presented to the Association at a regular meeting.

## By-Laws.

1. The Association shall maintain a publication.
2. Members shall be free to publish, in any way they desire, essays that have been submitted to the Association.
3. Reports of meetings of the Association, prepared under supervision of the Secretary, shall be sent for publication to such journals as the Council may direct.
4. The annual meeting shall ordinarily be in connection with the American Association for the Advancement of Science.

## MEMBERS OF THE ASSOCIATION OF AMERICAN GEOGRAPHERS.

December, 1912.

Charles C. Adams, University of Illinois, Urbana, Ill.
Cyrus C. Adams, American Geographical Society, Broadway at 156th Street, New York City.
Robert Anderson, 53 New Broad Street, E. C., London, England.
Wallace W. Atwood, University of Chicago, Chicago, Ill.
Robert L. Barrett, 109 Lakeshore Drive, Chicago, Ill.
Harlan H. Barrows, University of Chicago, Chicago, Ill.
Louis A. Bauer, Carnegie Institution, Washington, D. C.
Elliot Blackwelder, University of Wisconsin, Madison, Wis.
Isaiah Bowman, Yale University, New Haven, Conn.
Herbert L. Bridgman, *The Standard Union,* Brooklyn, N. Y.
Albert Perry Brigham, Colgate University, Hamilton, N. Y.
Alfred H. Brooks, U. S. Geological Survey, Washington, D. C.
Robert M. Brown, State Normal School, Worcester, Mass.
Henry G. Bryant, 2013 Walnut Street, Philadelphia, Pa.
Marius R. Campbell, U. S. Geological Survey, Washington, D. C.
Frank Carney, Denison University, Granville, Ohio.
Collier Cobb, University of North Carolina, Chapel Hill, N. C.
George E. Condra, University of Nebraska, Lincoln, Neb.
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Explanation of Plate I

Map of Alaska showing distribution of glaciers studied by the author in several expeditions to Alaska.

PLATE I

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EXPLANATION OF PLATE II

*a* Spencer Glacier with its alluvial fan of outwash gravels in the foreground, and the barren zone at *b*. Photographed during the dynamiting of the glacier ice. Photograph by A. W. SWANITZ.

*b* The terminal moraine of Spencer Glacier and the railway on the moraine and alluvial fan.

PLATE II




*a*

*b*

## Explanation of Plate III

*a.* The two dikes (d-d), the Alaska Northern Railway (r-r), and the alluvial fan of outwash gravels. Photograph by A. W. Swanitz.

*b.* Wreckage of twenty-one hundred foot dike after the glacial stream had broken through it.

a

b

## Explanation of Plate IV

*a*. Dry bridge where gravels had been deposited to a depth of fourteen feet. Photographed in 1911.

*b*. Curves in originally straight track, due to glacial stream aggradation. The man in the foreground is Colonel A. W. Swanitz, the railway engineer who accomplished the stream diversion in 1911.

*a*

*b*

Explanation of Plate V

*a*. Curves in originally straight track at a culvert where a team of horses could be driven beneath the track before the glacial streams deposited their gravels on the alluvial fan.

*b*. Bridge half abandoned by glacial stream in 1911 before the diversion.

# PLATE V



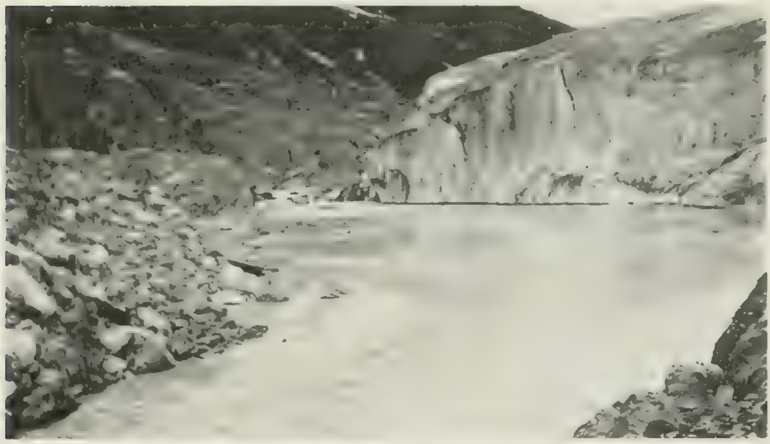
*a*

*b*

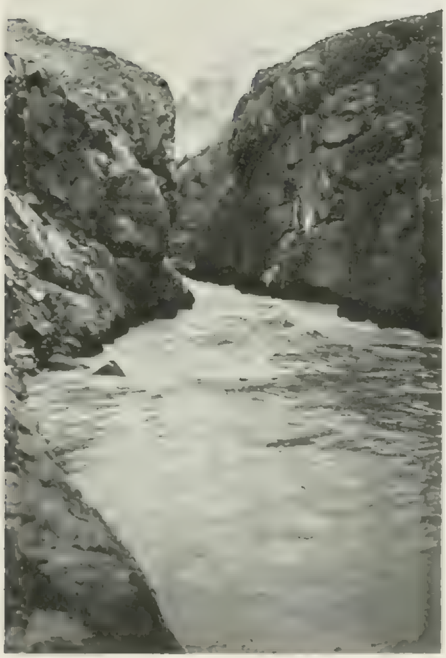
## Explanation of Plate VI

*a*. Stream emerging from beneath Spencer Glacier in June, 1911, before the diversion.

*b*. Stream plunging into box canyon before the diversion.



*a*



*b*

## Explanation of Plate VII

Rock dam in the box canyon produced by a single blast of dynamite in connection with diverting the glacial stream. Photograph by A. W. Swanitz.

PLATE VII

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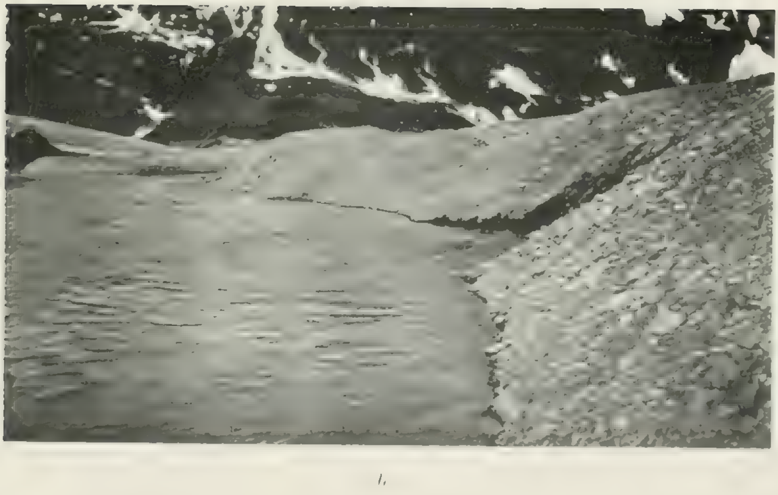
EXPLANATION OF PLATE VIII

*a* The stream disappearing beneath the glacier where the red dye was put in.

*b* Subglacial stream boiling up in the fosse.

a



b

## Explanation of Plate IX

*a* Shovelling out the ice fragments after a blast of four boxes of dynamite in the ice channel.

*b* Excavating the ice channel. Ice blocks floating away in water from the melting glacier.

*a*

*b*

## Explanation of Plate X

*a* The marginal channel (m); site of lower dam (n); the ice channel (o); the fosse (p-p); the bridge by which the diverted stream was crossed by the railway (q).

*b* The fosse, before the stream diversion.

PLATE X




*a*

*b*

EXPLANATION OF PLATE XI

Aperture by which the diverted stream disappeared beneath Spencer Glacier. Photograph by A. W. SWANITZ.

Explanation of Plate XII

Subglacial river where the diverted glacial stream cut down through the artificial ice channel to the natural tunnel below. Photograph by A. W. Swanitz.

PLATE XII

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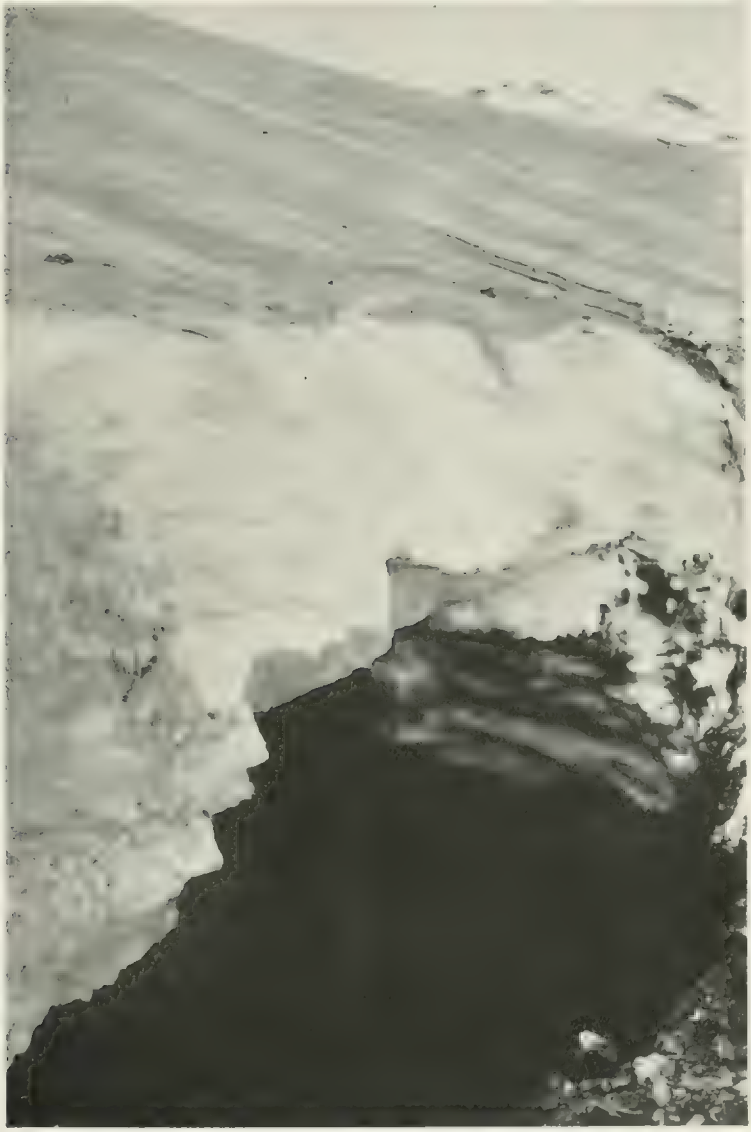


EXPLANATION OF PLATE XIII

*a* Lowland forest along lower part of La Laja Creek. Stream choked with aquatic vegetation.

*b* Lowland forest clearing at Cuatotolapam.

*a*

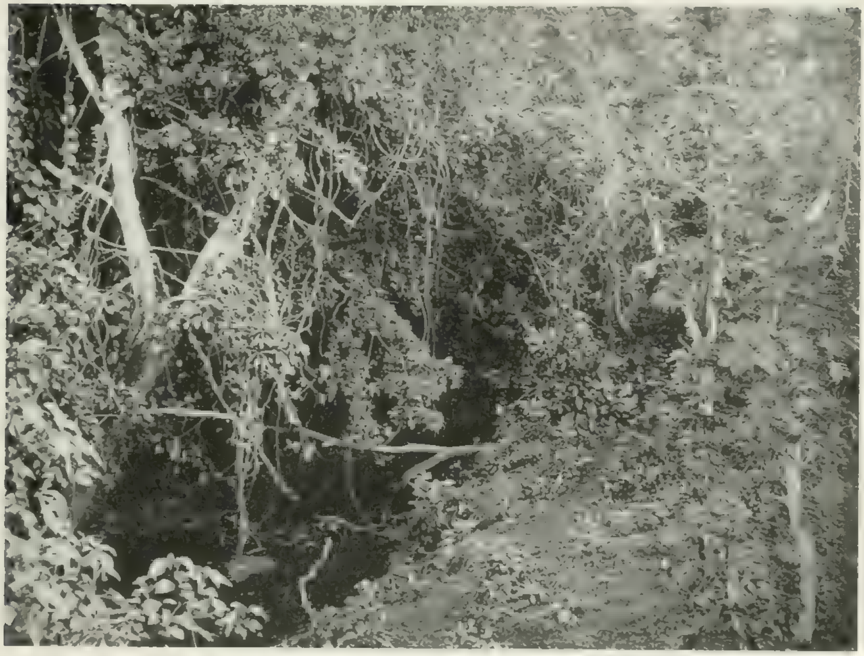
*b*

Explanation of Plate XIV

Upper part of La Laja Creek. Stream entirely covered over by dense vegetation.

PLATE XIV





## Explanation of Plate XV

*a.* General view of a stretch of savannah grassland at Cutotolapam.

*b.* A group of trees on the savannah, showing the "umbrella" form acquired in this habitat.

PLATE XV



a

b

Explanation of Plate XVI

Lowland forest clearing planted to cane.

PLATE XVI

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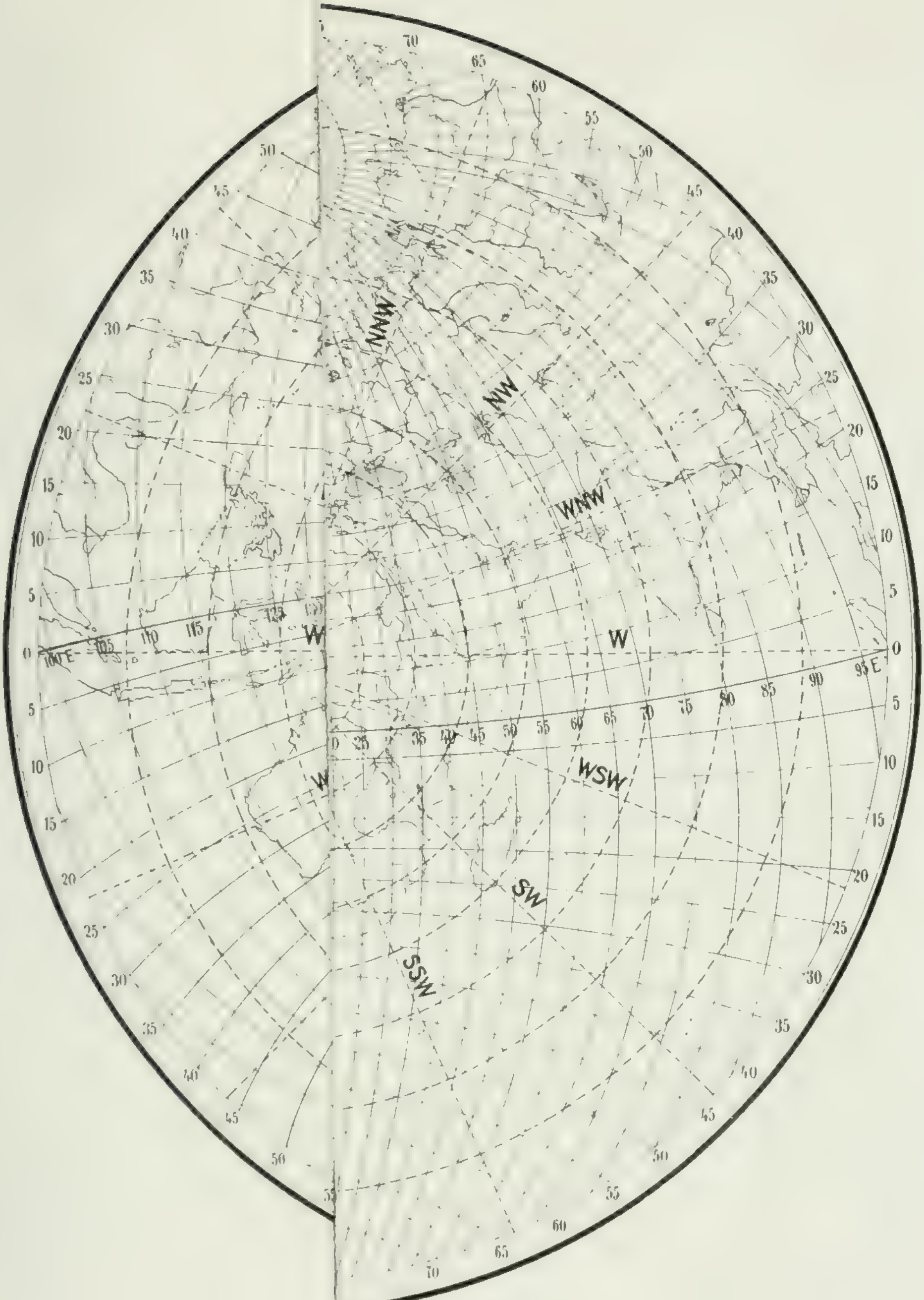
PLATE XVII

Mean scale (= scale of projected globe) 1:150,000,000.



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WSW
SW
SSW
100 E
95 E

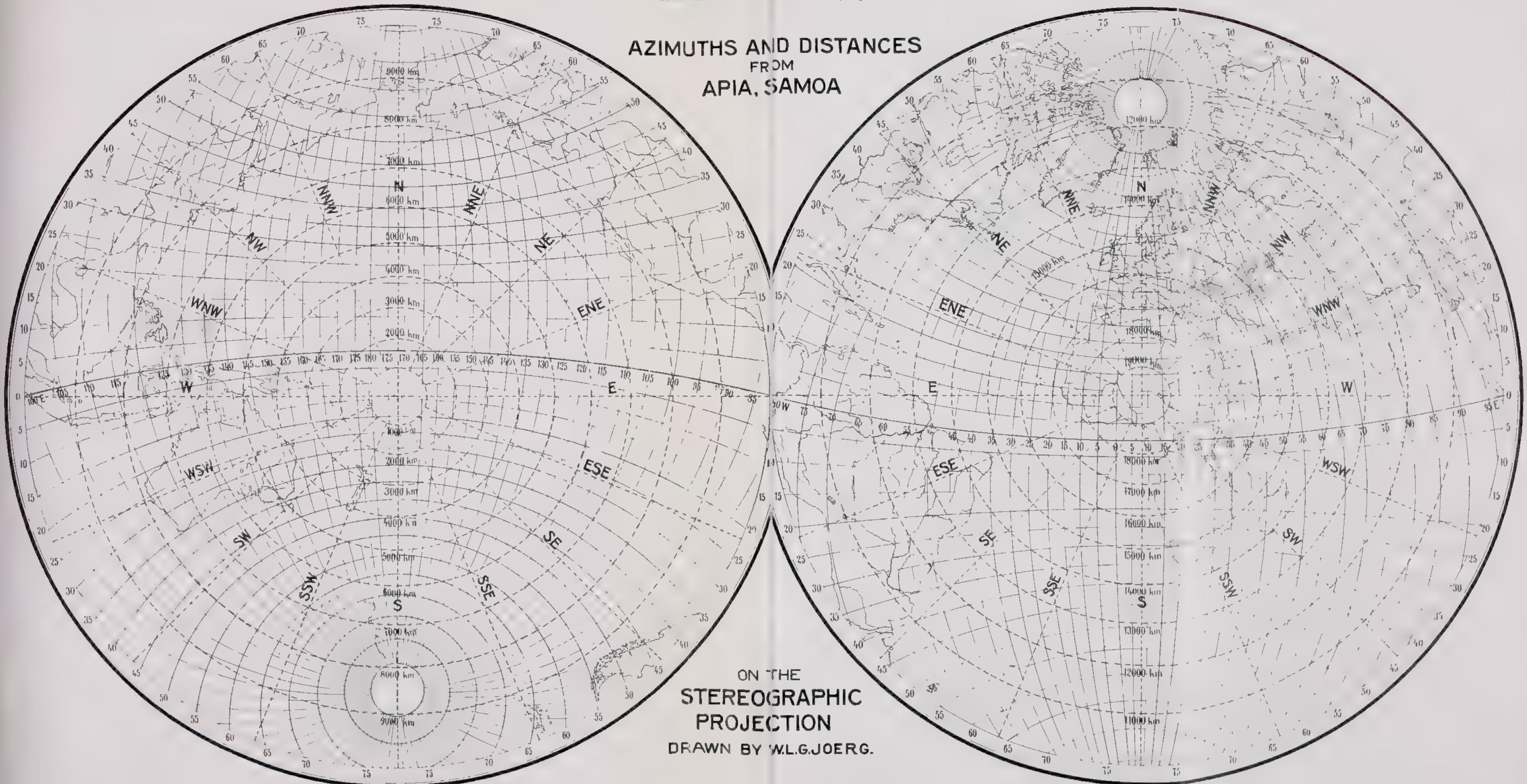
AZIMUTHS AND DISTANCES
FROM
APIA, SAMOA
ON THE
STEREOGRAPHIC
PROJECTION
DRAWN BY W.L.G.JOERG.

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PLATE I





RALPH STOCKMAN TARR

Annals of the Association of American Geographers
Volume III, pp. 3-28

# MEANDERING VALLEYS AND UNDERFIT RIVERS

W. M. DAVIS

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Underfit Rivers.—The chief object of this paper is to call attention to an explanation recently suggested for the peculiar relation that is frequently observed between the small-curved meanders of a river and the larger-curved meanders of its valley, a relation that has been called "underfit." Some geographers have doubted whether there was anything peculiar or abnormal enough in such a relation to demand special explanation; others believe that an underfit river must once have been of larger volume, so that its meanders could be of the same dimensions as those of the valley, and that the river after carving

the larger curves of its valley suffered loss of volume, as by beheading, climatic change, or some other cause. Evidently the underfit relation can occur only after a sufficiently advanced stage of valley development for the opening of a floodplain in the valley bottom, and before so far advanced a stage that the valley sides have lost distinct expression; that is, in full and late maturity; for during youth, before a floodplain is formed, the valley sides descend directly to the river banks and leave no space in which the curves of the river can depart from those of its valley; and in old age, after the valley sides have wasted away, there are no longer any valley meanders with which the river meanders may be compared.

Lehmann's Principle.—A new explanation of the underfit relation of a small-curved river to a larger-curved valley has lately been offered by Dr. Otto Lehmann of the University of Vienna. He told me of it during an inter-university geographical excursion in France in the spring of 1912, and has since then, when about to publish an account of it himself, authorized me to make such statement of it as may seem desirable. In now presenting it to American geographers, I wish to propose that the principle involved should be called—by those who are interested in the historical development of our science—Lehmann's principle, just as the production of coastal embayments by the partial submergence of a dissected land surface may be called Dana's principle; and the frequent dependence of flights of river terraces on defending rock ledges, Miller's principle; and so on. Lehmann's explanation is, in brief, that the failure of the curves of a river to fit the curves of its maturely opened valley is due to a gradual loss of volume by reason of an increasing underflow in the accumulating alluvial deposits which the river itself lays down on the widening valley floor, and of an increasing percolation through slowly widened crevices and passages in the underlying rocks. Lehmann's principle is therefore that rivers normally and spontaneously diminish in volume during maturity, because the alluvial underflow and the deeper underground percolation as normally increase. Before giving further account of this ingenious idea, a general statement regarding the evolution of river meanders and of incised meandering valleys will be introduced, in order to enter upon Lehmann's explanation of underfit rivers on the basis of a clear understanding of the points involved in it.

Initial Irregularity of River Courses.—There has been a needless amount of discussion of the origin of river meanders based on the false assumption that the initial course of a river is a straight line. No straight river occurs in a state of nature. Any young consequent river, newly established on a land surface not previously subjected to river action, must inevitably have an irregular initial course due to the unavoidable inequalities of the land surface. Such a land surface

may be a newly uplifted sea floor, a lake bed revealed by the withdrawal of the lake waters, a recent lava flow, or a drift sheet laid bare by the melting of a continental glacier. All such surfaces have sufficient inequality to give the consequent rivers which are established upon them some significant departures from the most unnatural of all courses, a straight line. It may be pointed out that a revived river on an uplifted peneplain does not here enter our problem, for it does not assume a new initial course, as some writers have implied. Such a river begins its new cycle of work along the course that it had developed when uplift interrupted the preceding cycle—except in the unusual case of uplift with so pronounced a tilting or warping that the pre-existent rivers are turned into new courses consequent on the new slant given to the uplifted surface; courses of this latter origin must necessarily be irregular and might be here considered; but they are rare and will therefore not be considered further.

Inasmuch as the initial irregularities of a young river are unsystematic, in the sense of having no relation to what may be called the intention or preference of the river that for a time adopts them, they have as yet received no special name. They will be here referred to as bends or turns. It is evidently not desirable that they should be called meanders; that technical term should be reserved for the rather systematic curves later developed by the action of the river itself and appropriate to its habit of flow.

Development of Initial Bends into Systematic Curves.—The path of the fastest current in a river departs from the medial line or axis of its channel, where it would flow if the river were straight and of symmetrical cross-section, toward the outer side of every bend; that is, toward the concave bank. Lateral erosion will therefore be stronger along that bank than along the opposite or convex bank, and the greatest depth of channel will be near the concave bank. Lateral erosion thus initiated will accompany downward erosion from the very beginning of the river's activity. Indeed if the velocity of a river is greater while reducing the fall of its too steep course during youth than afterwards when it attains a graded course of less fall in maturity, the centrifugal force expendible in lateral erosion during youth may be greater than in maturity; but the rate of lateral displacement of the river by lateral erosion will ordinarily be greater in late maturity when it takes place chiefly in unconsolidated alluvial deposits of the floodplain, than in youth when it takes place in the valley-side rock. In any case it is a mistake to say, as is sometimes said, that lateral erosion does not begin until after vertical or downward erosion has ceased. Instances may be pointed out in which, during a vertical erosion of a hundred feet or so, the lateral erosion of a river has been five or ten times as much.

The initial bends or turns of a river undisturbed by external accidents will be slowly expanded by lateral erosion, while the valley is slowly deepened by vertical erosion; and more or less of the eroded material will be laid down along the convex banks down stream from its source, as the river shifts laterally away from the convex toward the concave banks. Thus the initial sinuosity of the river course is spontaneously increased. As centrifugal force varies inversely with curvature of path, initial bends of short radius will usually be expanded more rapidly than those of long radius, and thus a similarity of curvature may be developed from many dissimilar curves. But it must not be assumed that every river expands every bend of its initial path; large rivers may soon obliterate the small bends of the channels and expand only the larger ones; none but small rivers will take such heed of all the little bends of their channels as to break up a large, slightly irregular bend into many small ones. This again tends to bring about a similarity of curvature, large rivers developing large curves and small rivers small ones. It must not be assumed that an increase over initial irregularity always involves an increase in radius of curvature; a gentle bend of long radius may be more worn by a good-sized river in one part of its arc than another, so that its long radius of curvature is for a time shortened; and this in a third manner tends to produce a similarity of curvature in bends that were initially dissimilar. Hence if a river acts without interference from external disturbances it should exert a selective action, whereby initial bends of many different patterns are brought towards a uniformity of curvature, and whereby a rough relation is established between size of river and size of curve. When this stage of progress towards organized development is accomplished, the further work of the undisturbed river will tend to enlarge its curves in arc as well as in radius; and the curves will then begin to deserve the name of meanders. Thereafter the belt included between lines drawn tangent to the curves, on the right and left of the general river course, may be called the meander belt.

THOMPSON'S PRINCIPLE.—Geographers have left it for a noted physicist, Professor James Thompson, of England, to point out an essential detail in the action of undisturbed rivers in meandering courses, whereby their meanders are systematically enlarged. His essay was entitled: "On the Origin of Windings of Rivers in Alluvial Plains" (Proc. Roy. Soc., London, xxv, 1876, 51), but its principle applies to winding rivers in their youth as well as in their maturity. On account of the centrifugal force of the flowing water, the curved river cannot have a level surface: the water must be slightly higher at the outer or concave bank than at the inner or convex bank. The greater the velocity of the river and the shorter the radius of its curves, the more pronounced must be the slant of its surface. But the bottom

water, moving more slowly than the surface water on account of friction, will not have sufficient centrifugal force to withstand the greater pressure exerted upon it by the higher water near the outer bank, and will therefore be given a component of motion toward the inner side of each curve; and in virtue of this it will flow obliquely across the bottom toward the inner bank. This will lower the water surface near the outer bank; and thereupon the surface water will gain an outward component of motion, and its flow will be directed obliquely toward the outer bank. The oblique motions thus instituted will aid in the erosion of the outer bank and in the transfer of the eroded material towards the inner bank.

Down-stream Migration of Meanders.—The enlargement of river meanders does not take place equally all along the outer bank of each curve. As a river flows into a curve, a certain time is required for the advancing current of fastest flow to be fully displaced toward the outer bank; hence outward erosion does not begin in full strength at the beginning of the curve. Similarly at the end of a curve, a certain time is required for the displaced line of fastest flow to regain its medial position; hence work on the eroded bank is continued beyond the end of a curve. If the curves are close set without connecting tangents, the line of fastest current, when it enters a curve to the right, will still have the lateral displacement due to its passage around the preceding curve to the left. The right-hand curve will therefore, under these conditions, be eroded on its inner or convex bank for a little distance beyond its beginning. The failure of the river to begin erosion of the outer bank at the beginning of a curve and the tendency to continue erosion of a given bank into the next curve result in the slow displacement of all the curves down the river valley. A young river must therefore, as soon as its initial bends are developed into somewhat systematic curves or meanders, be conceived as not only deepening its valley, but also as enlarging every curve, widening the meander belt, and pushing the whole system of curves down-valley. The down-valley migration of meanders, as it may be called, has probably been long known to engineers, but it has only lately found its way into text books of physical geography. It would be interesting to learn who first announced this principle.

Amphitheaters and Spurs.—If vertical erosion is now more explicitly taken into account along with lateral and down-valley erosion, it will be seen that a valley eroded by a young consequent river of well-defined curves must possess a number of systematically related features. The river may still be interrupted by frequent rapids, between which graded stretches will have been developed: but even at this early stage under-cut, steep-walled amphitheaters will be excavated around the outside of each curve, alternately right and left; and into

each amphitheater a sloping spur will descend from the opposite valley side. This is a well-established and familiar matter, truly, yet not so fully used in the description of valleys as its systematic value warrants. Because of the down-valley migration of river curves, a steep amphitheater wall will begin on its up-valley arm and not reach its full height for a moderate distance beyond the beginning of its concave curve. It will also extend with decreasing height around the end of its curve and along the up-valley side of the next spur, which will be undercut and steepened down to river level. Each spur will therefore be trimmed off along its up-valley side, while its down-valley side will have a gentler slope where the river has withdrawn or slipped off from it; the slopes on the two sides of a spur may therefore be called the undercut and the slip-off slopes. As a result of this dissimilarity of form, the aspect of a young or early mature meandering valley will be different according as the observer looks upstream or downstream. In the first case the gentle slip-off slopes may show a succession of cultivated fields; in the second the abrupt undercut slopes may show a succession of wooded scarps. The gentlest slope of a spur will usually be along its axis, about at right angles to the general course of the valley; its declivity will give a good indication of the ratio between lateral and vertical erosion during the period of valley deepening; and as noted above this ratio may be as large as five or ten to one. The axial and slip-off slopes of the spurs may be thinly covered with river-worn gravels and sands, irregularly strewn and obliquely bedded; no such deposits are to be expected on the undercut slopes of the spurs and amphitheaters. Excellent examples of undercut spurs are given by Marbut, who notes the widening of the meander belt, but apparently does not recognize the down-valley migration of the meanders (Missouri Geol. Survey, vol. x, 1896, 104-107).

Development of Floodplains.—A consequent river will eventually wear down its ungraded rapids and deepen its valley along the greater part of its length sufficiently to establish a continuously graded course, in which all the previously graded stretches, now more deeply degraded, are united; and on which its capacity to do work, in the way of eroding its banks and of transporting its load, will just equal the work that it has to do. It may then be regarded as passing from youth to maturity. Further change in the fall of the river is very slow; yet it must take place, even though the river still maintains a graded condition; for the river volume, which is a factor in carrying power, and the load which has to be carried, are both variable quantities. If the load increases during maturity because of increasing ramification of side streams, the valley floor must be slightly aggraded in order to maintain the balance between carrying power and load; later on, when load decreases with the decrease of relief in the approach of old

age, the valley floor must be slowly degraded—unless compensation is accidentally maintained by a loss of river volume due to decrease of rainfall with waning altitude of drainage area, as the theory of the cycle of erosion demands, and to withdrawal by underflow and percolation, as Lehmann's principle suggests. These slow changes of valley depth may, however, be neglected for the present, while we consider the further effects of lateral erosion, whereby the valley floor is widened.

The river is assumed to be still working in the enlargement of the fairly regular set of curves, previously developed, and to work undisturbed by external agencies. The enlarging curves will better and better deserve the name of meanders as their arc increases. The river will continue to undercut the amphitheater walls and the up-valley sides of the spurs; but as valley deepening has now practically ceased, the lateral shift of the river will withdraw it horizontally from the base of the axial and slip-off slopes of the spurs, and sediments will thereupon be laid down to fill the evacuated space; for there the water runs slowest, and unless the space were filled the cross-section of the river would increase, its velocity would decrease, and the graded condition would be destroyed. Strips of floodplain will thus be systematically developed along the convex banks, alternately right and left, around the end and along the down-valley side of the spurs. The strips, narrow at first, slowly gain in width; they are gracefully curved upstream at their spur-end beginning, and down-stream at their end under an amphitheater wall. Their pattern suggests that they should be called scrolls; they may be described as narrow or wide, according to their stage of growth. As a result of the down-valley meander migration, the tributary streams, that may have once entered the river at the end of a spur or a floodplain lobe, will in time be overtaken by the next up-stream meander and will enter its outer curve (See note in Geol. Mag., London, 1903, 145-148).

Changes in Amphitheaters and Spurs.—Along with the widening of the floodplain scrolls, the amphitheaters must be enlarged, elongated and opened, and the spurs must be more and more undercut and consumed. At first during the deepening of the valley, when but little of the original breadth of the spurs has been lost, they may be called trimmed; later on, when floodplain scrolls are widening and the originally rounded end of the spurs is narrowing to a cusp, they may be called sharpened; still later, when they have nearly disappeared, perhaps blunted is as good a term as any other. At the same time the amphitheaters are elongated by the down-valley advance of the river meanders; and the elongated amphitheaters are opened by the consumption of the separating spurs. Let it be noted in passing that the three terms trimmed, sharpened, and blunted, have an evolutionary

value, in implying that the trimmed spurs were once wider, that the sharpened spurs were once duller, and that the blunted spurs were once sharper; they are therefore explanatory, not empirical terms. Likewise, the terms, elongated and opened as applied to the amphitheaters are explanatory. Blunt, sharp, long and open are empirical terms.

Widening of a Floodplain.—The further progress of undisturbed river work after the blunting of the spurs and the opening of the amphitheaters involves a slow widening of the valley floor to a greater width than that of the meander belt, so that the river shall no longer swing against the two valley sides at every double meander. It thereafter undercuts one side here, the other side there, in irregular instead of in systematic fashion. Its course thus comes to wind more and more freely through the widening floodplain, and at last swings but rarely against the valley-sides. Changes in its course are then much more rapid than when it was working against rocky side-walls. The lower Mississippi is now in this late stage of development. Jefferson has examined the maps of a number of rivers with respect to the "Limiting Width of Meander Belts" (Nat. Geog. Mag., 1902, 373-384), and finds that on open floodplains the width of the meander belt averages eighteen times greater than that of the river.

Cut-off Meanders.—It has been assumed, and with good reason, that during all the time of undisturbed meander development, the river has been sweeping smoothly around every meander curve and expanding all the curves in thoroughly competent fashion. Many rivers do flow and work in this fashion. Each meander must slowly grow to greater and greater size, increasing in arc as well as in radius, until the neck of a valley-side spur or of a floodplain lobe is narrowed and worn through. Then the roundabout meander is cut off and abandoned; the river adopts the shorter course instead of continuing on the longer one. The river length, thus far slowly increasing, then suffers a sudden loss equal to the perimeter of the cut-off meander. Cut-offs may occur during the youthful stage of a narrow, deepening valley, as well as in the mature stage of a graded and broad-floored valley. In the former case, the continued deepening of the valley after the cut-off has been made will soon leave the abandoned roundabout valley curve above the river level. The Meuse in northeastern France shows good examples of this kind; two examples are reproduced from the Etat-major map of France in my Geological Essays (p. 597).

A new meander will be gradually developed to replace the lost one, and this reproductive process may involve a somewhat systematic series of changes, as has been shown for the Mississippi by W. S. Tower in a study of "The Development of Cut-off Meanders" on the Mississippi (Bull. Amer. Geog. Soc., 1904). Hence an undisturbed meandering river ought to pass through periods of gradually increasing

length alternating with moments of sudden decrease, the variation in length thus caused being confined within fairly constant limits. This is certainly true for the Mississippi. When a cut-off occurs on a floodplain and the meander is left as an ox-bow lake, it will usually possess a radius of maximum length; the other meanders, not yet enlarged to the cut-off stage, are therefore as a rule of smaller radius than the ox-bows. The meanders and ox-bows of the Mississippi confirm this expectation.

Meanders of Large and Small Rivers.—The attainment of a freely meandering course on an open floodplain will of course demand a longer time from a small river working in hard rocks than from a large river working in unconsolidated sands or clays; but under the undisturbed conditions here assumed even a small river must eventually fulfil its destiny of enlarging all its curves, one after the other, to the cut-off stage. It will mature more slowly than a large river, but the features of maturity should be much alike in both cases, except in dimensions. If there be important differences in actual examples of large meandering and small meandering rivers, the differences are more likely due to the greater number of accidental disturbances by which a small stream is disturbed during its slow and feeble development, than to any inherent difference in the principle of undisturbed meander development as applied to streams of different size. A small undisturbed river must expand its meanders to larger and larger radius and longer and longer arc, until cut-offs prevent further enlargement. Wherever the meanders are far enough separated to have free space for growth—and certainly they ought sometimes to be wide spaced in small rivers, if they originated only in the initial irregularities of the river's course—they ought to attain a large radius of curvature even in a small river. But the fact that small rivers do not have large-curved meanders indicates that the conditions of no disturbance, here assumed, do not occur; thus we approach a principle of prime importance—namely, that the small meanders of small rivers and the large meanders of large rivers are not so much the result of the river's own action, as of its reaction to the external disturbances to which rivers are subject If initial bends and turns are treated as external disturbances, acting in the ways already explained, this principle will be all the more completely assured. Hence our next problem is to consider the nature of external disturbances and their effect on river behavior.

Variations in Rock Resistance.—Freedom from external disturbances, thus far assumed, is unnatural. No river is left free to develop meanders according to its own intention. One of the commonest external influences is found in diversity of rock resistance along a river course, whereby lateral as well as vertical erosion is made easier in

one stretch than in another. The variety of disturbing conditions thus introduced is so great that no general treatment will cover all of them; each case must be discussed for itself. Yet unless contrasts of rock resistance are wide-spaced and pronounced and the river is small and feeble, the effect of varied rock structures, acting alone, is comparatively small as far as the forms of meanders is concerned. Thus in the highland of the Ardennes, composed of greatly deformed and somewhat unequally resistant rocks, the deeply incised meanders of the Meuse are finely developed; those of the Ourthe and Semois are still more remarkable in the perfection of their curvature and the length of their arcs. It does not seem possible that these extraordinary meanders, which must have begun their development much above the depth to which they are now incised, should be determined to any significant degree by the folds of the deformed strata, as has been suggested, or by inequality of resistance.

Pronounced but close-spaced differences of rock resistance may possibly cause local exaggerations of meander curves: for if a weak structure happens to lie on the outside of a curve, the curve may be locally expanded into it. It may, however, be doubted if this is a frequent cause of meanders; for a local expansion of a curve would soon be checked by river-swept gravels, after which its further enlargement would be slow; just as a local deepening of the channel in weak rocks usually comes to be gravel-covered when the river course through it is graded. In both these cases, the next down-stream strong rocks exercise a large control on the amount of erosion that the river can accomplish in the adjoining weak rocks.

When variations of rock resistance are strong and wide-spaced, they will produce the familiar result of accelerating river development in the weaker structures and retarding it in the harder structures; thus a maturely developed series of floodplain scrolls, systematically placed in relation to the accompanying amphitheaters and spurs, may be already formed where a river traverses a wide belt of weak rocks, while the same river, farther down stream in more resistant rocks, is still in the youthful stage of valley deepening, without any floodplain.

Anomalous River Meanders.—Marbut calls attention to the sharpening of meanders into cusps where lateral erosion is facilitated by the entrance of a small tributary valley (Missouri Geol. Survey, vol. X, 1896, p. 109). Peculiar kinks, for which no explanation is current, are mapped in the free meanders of the Theiss on its broad floodplain in central Hungary: one of its branches, the Koros, is so excessively sinuous that the meander belt itself meanders.

An altogether exceptional case is offered by the Connedogwinet, a branch stream which enters the Susquehanna from the west near Harrisburg. It flows in a mature valley of half-turn meanders incised to

a moderate depth beneath a peneplain; the valley floor has a floodplain a few hundred feet wide. One striking feature of the case is the excessive length of the rectilinear tangent by which the half-turn meanders are united; another is the path of the stream along the base of the slip-off slopes of the spurs, and hence on the up-valley side of the floodplain scrolls, while the floodplain scrolls lie along the undercut spur slopes. So far as I know, attention has only once been called to these features as abnormal departures from the systematic habits of most rivers in incised meandering valleys (Proc. Amer. Phil. Soc., xli, 1902, 251); no satisfactory explanation for them has yet been offered.

Landslides, Tree-Falls and Sod-Slips.—Among the most common accidents by which the regular growth of river meanders is disturbed is the invasion of the river channel, particularly on the concave bank, by sliding rock-waste, falling trees and slipping sods. Young rivers, deeply incised in a highland, are frequently more or less clogged in their narrow channel by landslides, rock-falls, talus cones and delta fans, whereby the development of smooth curves, alternately right and left, is much embarrassed and may be entirely checked. Such rivers are battered about, now on this side, now on that, and hence have no opportunity of developing serpentine courses. The comparatively rectilinear course of certain rivers, deeply intrenched in elevated highlands, is perhaps due to the impediments which landslides from undercut slopes and inwashed waste from side ravines have offered to an expansion of the bends and turns with which the river began its work. If this supposition be permissible, we may imagine cases in which the initial bends and turns, instead of being expanded during the incision of a deep-cut valley, are diminished and possibly extinguished. The ratio between the power of the river, as determined by its volume and fall, and the quantity and nature of falling rock, as determined by rock structure and by rate of regional uplift, must evidently be of large importance in such cases.

It is thus conceivable that such a river as the Colorado may have been prevented from developing meanders in certain stretches of its canyons by the overwhelming descent of landslides whenever and wherever the river attempted to enlarge a turn to one side or the other; for landslides ought to be most plentiful just where the river undercuts the canyon walls. The vigorous forward growth of boulder deltas from side canyons might contribute to the same result, for they form narrows in the river. Yet some of the upper canyons of the Colorado are mapped in very sinuous courses, and in such canyons rock-falls from the undercut amphitheater walls have evidently not prevented the river from developing its meanders and widening its meander belt. Possibly, as above suggested, the nature of the rock in the canyon walls,

and the degree to which it is shattered when it falls into the river may have something to do with the meandering habit of the river in some canyons and its nearly rectilinear habit in others. Certain it is that the cross-bedded sandstones of the White cliffs in southern Utah have very little talus at their base; while other sandstones of that region supply a heavy talus of large blocks. Powell's account of Labyrinth canyon, where the river "nearly doubles on itself many times" (Exploration of the Colorado River of the West, 1875, 52), does not give details as to the nature or amount of talus at the base of the undercut amphitheaters, but states that the canyon "is cut through a homogenous sandstone" (170), which I take to be of the same age as the sandstones of the White cliffs. Where this homogenous sandstone is actively sapped by the retreat of the weak underlying beds beneath the south-facing cliffs of the great cuesta through which the canyon is cut, "huge blocks . . . have fallen from the upper part of the escarpment" (173); whether such blocks occur in the canyon, where the weak underlying beds have dipped northward beneath the river, is not stated.

In a more mature stage, the irregular formation of a sand-bar in the channel, especially in the tangent between two meanders, may split the current and cause a new curve to be begun by the larger part of the stream. This process has been described by E. F. Fisher, who calls it the partition process (Proc. Boston Soc. Nat. Hist., xxxiii, 1906, 16—).

Relation of River Volume to Meander Radius.—The most important point, however, to be here noted is the different effect of an accident of given strength on rivers of different size. A large river will be utterly indifferent to an accident which will easily suffice to turn a small stream from its course. A small stream may be thrown into new contortions by a sod-slip, but the Mississippi takes no notice of caving banks, even when they carry large trees into its vast flood. It is this capacity of trifling accidents to produce new curves in the course of little streams, already somewhat sinuous because of the development of small curves from small initial bends and turns, that explains why such streams run in small, close-set meanders, which, being close-set, must be cut off before they grow large; and it is the indifference of great rivers to small accidents, as well as to small initial turns and bends, that allows them to select only the wide-spaced bends and turns for development into large meanders, which, being wide-spaced must grow still larger before they can be cut off under the action of a river so great that little accidents do not affect it. However few and simple the initial bends of a little stream, it must soon develop many new curves because of the many small accidents that will deflect it—unless indeed, as suggested above, the accidents are

so serious and so plentifully and impartially distributed along both sides of its course, as to prevent the growth of curves instead of promoting them. However small and numerous the initial bends of a great river, and however abundant the trifling accidents that later happen along its course, it will overcome all these small affairs, and pay heed only to the larger ones.

Incised Meanders of Revived Rivers.—When a river, which has already established a meandering habit on the open floor of a mature or old valley, is impelled to renewed vertical erosion by regional uplift, the conditions analyzed above for a young river again find application; but in the present case the revived river begins the incision of its valley in the new cycle with a system of meanders already developed, instead of with the irregular bends and turns of a new young river. The incised course of a river, revived from a previous maturity or old age, should therefore exhibit many regular curves with more systematically carved amphitheaters and better trimmed or sharpened spurs, than those of its first youth. Jefferson states in the article cited above that the meander belt of incised rivers in meandering valleys averages 30 times the river width; on open floodplains this ratio is 18. Ramsay was one of the first to draw attention to incised meandering valleys, two of the examples that he adduced being the Wye in England and the lower Seine in France (Phys. Geol. Geogr. of Great Britain, 1874, 242). It does not, however, seem to be necessary always to assume that meandering valleys require two cycles of erosion for their development; for a meandering course may be assumed during the gradual incision of a first cycle valley as Winslow showed (Science, xxiii, 1893, 31), and as has here been explained in an earlier paragraph; and curiously enough it does not always seem to be the case that the revival of a mature or old, and hence presumably meandering river will result in producing a meandering valley; for some uplifted peneplains are trenched by comparatively straight valleys, although the rivers of a peneplain before uplift ought, from all that we can infer of old rivers, to have had a meandering habit. It may be here pointed out that the presence of a cover of unconsolidated deposits on a peneplain, as an aid in the development of meanders to be afterwards incised in the underlying rocks as the result of regional uplift, does not appear to be necessary; rivers on a peneplain must, before its uplift, be in their extreme old age, and old rivers ought to be of meandering habit. No special conditions need therefore be postulated to account for the perfectly expectable occurrence of an incised meandering valley in an uplifted peneplain; it is the absence of meanders in young or submature valleys incised in uplifted peneplains that demands special explanation: no satisfactory explanation of their absence has yet been given. Increase of

velocity as a result of uplift, to which some authors appeal as a means of rectifying a river, should rather increase its sinuosity.

The smaller the ratio of depth of valley incision in an uplifted peneplain to radius of river meanders, the more distinctly will the new valley, as well as the river at its bottom, meander in the youthful and submature stages of the new cycle. Hence incised meandering valleys—that is, valleys limited by meandering margins of the uplands, right and left, beneath which they are entrenched—are best seen where large rivers, revived from an advanced stage of development, have cut new courses in moderately uplifted peneplains. If the depth of incision is great and the meander radius is small, the valley, as defined by the top of its walls, will not meander to any significant degree, although the stream at its bottom may be very sinuous. Furthermore, the course of a river in a well-developed incised meandering valley must not be conceived as having been cut down vertically beneath the course that it had before its revived erosion began; for during its new cycle of work, its meanders must have expanded in radius and arc and its whole system of curves must have been pushed down valley. The reconstruction of the former river course in a meander belt of less width and with curves farther up-valley, may be attempted by connecting the contours of the slip-off slopes on successive spurs, right and left. This problem is discussed in one of my earlier papers on "Incised Meandering Valleys" (Bull. Geogr. Soc. Phila., iv, 1906).

Underfit Rivers in Incised Meandering Valleys.—We may now enter upon the more special subject of this paper. The best cases of underfit rivers are found in well-defined incised meandering valleys, the floors of which have a breadth sufficient to allow the river to wander in a more irregular path than that of the curved valley. The valley must therefore be further developed than in its youth, when no flood-plain has been formed, and not so far as in its old age, when all definition of meandering course has vanished; that is, the valley must be in its maturity. The underfit rivers of such valleys wander aimlessly in small curves in the regularly meandering larger curves of the valley floor, instead of systematically following the base of the amphitheater walls and of the undercut spur slopes, and thus normally continuing the former widening of the valley floor. They now touch or abandon the valley sides anywhere or nowhere in the most arbitrary and haphazard fashion. A number of examples of this kind will be presented farther on.

Underfit Rivers and River Floods.—Some geographers who do not regard an underfit river as indicating a secular diminution of river volume, explain the larger curves of the valley by the action of the river when in flood. This has never seemed to me a successful explanation. If the pattern of a meandering valley is due to the work

of its river when in flood, the river channel should systematically follow the base of the undercut slopes, and the river at low water would have to get along as well as possible in such a channel. Such is the case in certain meandering valleys that I have seen in the subarid plains of North Dakota, where the variation from flood to low-water stage is strong; but even at low water the streams of such valleys would not be called underfit, in the sense here given to that term. The only conditions under which a low-water channel could depart in underfit fashion from the base of the undercut walls in a meandering valley that owes its large curves to the work of flood waters, would be in a region where floods came so rarely that the low-water stream, gradually aggrading and wandering away from the flood channel, could develop an underfit course for itself during the long intervening dry weather periods; and even in such regions, the low-water streams would, for a certain time after a flood, follow the fit course of its deep channel.* The special conditions of long droughts and rare floods do not obtain in valleys where underfit rivers are observed: the river floods there spread inefficiently—as far as the pattern of the valley is concerned—over the valley floor; they doubtless modify the course and the curvature of the underfit low-water channel, but they do not transfer it to the base of the undercut slopes; yet along the base of those slopes a river must have run when the systematic features of the valley were developed. Of course, so long as the features which are here described as systematic—namely, the steep walls of the amphitheaters, the alternating spurs of trimmed, sharpened or blunted forms, and the associated narrow or broad floodplain scrolls fitted in orderly fashion around the ends and along the slip-off slopes of the spurs, right and left, down the river course—are looked upon as arbitrary or accidental, the haphazard departure of an underfit river from the base of the undercut slopes would not excite wonder or call for inquiry. It was therefore for the purpose of explaining and establishing with some detail the origin of the normal forms seen in an incised meandering valley that the earlier pages of this article were written; for only when one is convinced that such valleys really do exhibit normal forms, and that such forms can be developed only by the systematic action of a fit river, working competently in curves of the same dimension as those of its valley, will the irregular course of underfit rivers excite surprise and demand investigation.

* A case of this kind is reported by S. S. Visher, in "An Example of Storm Erosion in the Badlands" of South Dakota (Journal of Geography, xi, 1913, 294-296). A violent flood swept away the smaller trees of a canyon floor, thus showing that the flood was an exceptional and not an annual occurrence. "Where formerly the stream had been winding, it was now straightened"; hence the winding of the former stream, a small one which "trickled the full length of the canyon," must have been self-developed since some previous master flood.

River Capture and Underfit Rivers.—Let a branch, AB, Figure 1, of one mature river, CD, capture and divert the upper waters, EA, of another mature river, EF; then the lower or beheaded portion, AF, of the second river, being necessarily diminished in volume by the loss of its upper waters, must aggrade its valley floor; and as soon as its former channel is thus obliterated, the beheaded river ought to develop an underfit relation to its previously carved valley-curves, in the sense of meandering irregularly on the aggraded floor in curves of a smaller pattern. Conversely, the capturing branch, AB, and its river, BD,

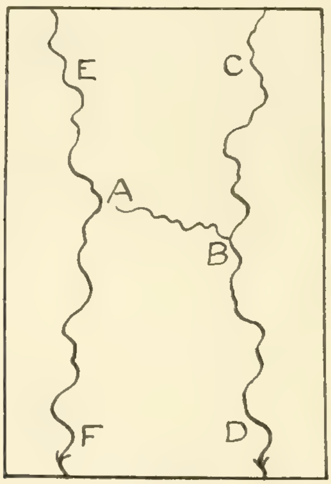

Fig. 1.

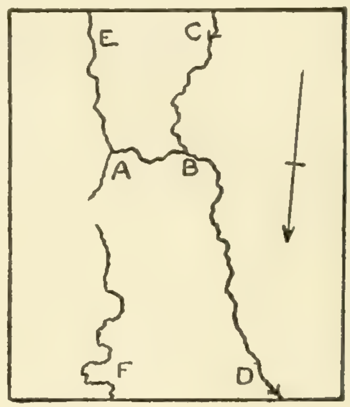

Fig. 2.

below the entrance of the capturing branch, being increased in volume, should exhibit for a time an overfit relation to their valley curves, in the sense of actively enlarging them: this will be particularly evident for a moderate distance below the elbow of capture, where volume is increased in largest proportion. The upper waters, EA and CB, of both rivers should still fit the curves of their valleys, but the diverted upper waters, EA, should, while establishing a new graded slope, incise their course beneath the former valley floor upstream from the elbow of capture, as if revived by uplift; such streams may be described as revived by capture.

In a good number of observed examples, some of these deduced changes are verified and others are not. In case of the Aisne-Aire in northern France, simplified in Figure 2, the Aire, EA, was captured by a branch, AB, of the Aisne, CD,—the Aire being thus transferred from the system of the Meuse to that of the Seine—here the beheaded lower course, AF, of the former Aire, known as the Bar, offers a very striking example of underfit behavior; it was indeed this example, as shown on a sheet of the excellent Etat-major map (1:80,000) of

France—reproduced in my Geographical Essays (p. 610)—that first drew attention to this subject some twenty years ago. But the Aisne below as well as above the point, B, where the diverted Aire, EAB, joins it, is also underfit, though to a less degree than the Bar. Again in the long known example of the diversion of the upper Moselle, MN, Figure 3, to the lower Moselle, NO, from its former path, NP, as a tributary of the Meuse, RQ, the Meuse is conspicuously underfit in its upper course, RP, above the former entrance of the upper Moselle as well as below, PQ. Evidently, then, some other cause than

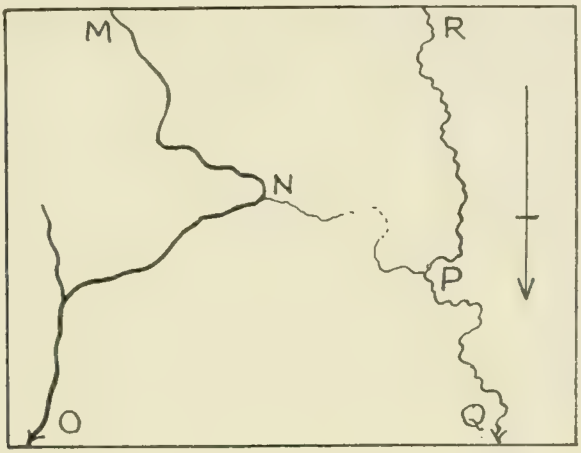


FIG. 3.

loss of volume by capture must have operated in these two cases. Yet a study of the headwaters of the Aisne and of the Meuse, as represented on the French maps, fails to reveal any recent loss by capture. Various other underfit rivers are also known, in which no signs of loss by capture are found.

CLIMATIC CHANGE AND UNDERFIT RIVERS.—If rivers were made underfit by a change from greater to less rainfall, all the rivers of a large region, so far as their valleys are appropriately mature, ought to become underfit, because a climatic change of this kind cannot be regarded as locally limited to certain river valleys. As a matter of fact, certain rivers remain competent to follow their valley curves in regions where others have become incompetent or underfit.

A possible cause of diminished run-off, resulting in an underfit river habit, may be found in increased evaporation as a result of clearing and cultivating an originally forested region; but no definite conclusion has been reached in this direction.

LEHMANN'S EXPLANATION OF UNDERFIT RIVERS.—The peculiar merit of Lehmann's explanation of underfit rivers lies in the normal and spon-

taneous operation of the processes which it invokes; and these processes are moreover so simple and expectable that the underfit habit of rivers in maturely incised meandering valleys might have been definitely deduced and predicted years ago as an ordinary, normal occurrence, had geographers developed the use of deduction along with observation as fully as astronomers have.

Loss of Surface Flow to Deep Percolation.—When a new land surface is offered to the action of rain and rivers, or when a land surface already normally advanced to its maturity or old age is uplifted so that a new cycle of deeper erosion is introduced, some of the surface water penetrates underground and finds its way for a less or greater distance through fissures and other minute passages in the underlying rocks. Although the percolation of water through such passages is slow, its long continued action may gradually open the passages and facilitate underground movement, whereupon the proportion of percolating underground water to flowing surface water will increase. In limestone districts the underground passages, enlarged rapidly by solution, may in time dispose of all the rainfall that is not evaporated, and surface streams in such districts will then disappear. In other kinds of rocks, less subject to removal by solution, the variation in the proportion of surface flow to underground percolation during the progress of a cycle of normal erosion is not yet known, but it seems reasonable to suppose that underground percolation may increase from youth to late maturity. In old age, however, although underground passages may be then well opened, the reduction of the general land surface to low relief will diminish the "head" of pressure to which the slow movement of underground waters is due; hence, through this late stage of the cycle, even though a good volume of water may then be stored in the underground passages, its movement may be so slow that the surface waters will regain the large proportion of run-off to rainfall that they had in youth—except that loss by evaporation from the slow discharge of the run-off in old age may be large. If such a restoration of volume occur, we should not expect to see it accompanied by a return to a fit or competent relation of river to valley; for in old age the valleys will have lost all their mature definition by the wasting away of their sides; the rivers will then wander freely over broad floodplains, and however far the lost river volume is regained, the terms, fit, underfit and overfit, will find no application.

Loss of Surface Flow to Shallow Underflow.—In addition to loss of surface water to deep underground percolation, there is a loss to shallow underflow, as soon as the accumulation of alluvium on the valley floor in maturity allows some water to creep slowly along at a small depth beneath the floodplain surface. This loss is relatively negligible in the early youth of rivers which are working in firm

rocks, for the bed and banks of their channels will be rock-bound and almost free from alluvium. But when the graded condition of maturity is reached and the river continues its lateral erosion without further valley deepening, the widening floodplain then developing on the mature valley floor will consist of alluvium about as deep as the river at time of flood. The lower part of the alluvium, lying unconformably on bed rock, will consist for the most part of the largest cobbles and coarsest gravels that the flooded river can sweep along; for these coarse materials are the first to be laid down on the bed of the temporarily deepened flood-channel as the high waters begin to subside. The upper layers of the alluvium, on the other hand, will consist of sands and silts which the laterally shifting river lays down on the inside of its meanders, or which the slowly subsiding overflow waters strew over the floodplain. With the first formation of such deposits, that is, with the first development of narrow floodplain scrolls as the valley passes from youth to maturity, a loss of surface flow to underflow must begin; with further widening of the flood-plain scrolls the loss of surface water to underflow must increase; and from the beginning of this loss a curious series of reactions is set in operation, whereby the loss of surface waters is still further augmented; but with the approach of old age and diminution of "head," the underflow, although holding a considerable volume of water, presumably becomes so sluggish that the surface may again, as in youth, dispose of nearly all the run-off. The reactions just mentioned must be further considered.

While a young river is still deepening its valley, its alluvial deposits will occur only in small and disconnected channel-pockets, and the underflow that locally passes through them may be neglected. When the river is just attaining the graded condition, its carrying power is already diminished below the measure previously possessed, because the impetuous current of steep-channelled youth is now reduced to the temperate current of graded maturity. The diminution of carrying power, however, should not be inferred directly from the diminution of velocity, still less from the sixth power of the diminution, for the tempered current of maturity has a larger cross-section than the impetuous current of youth, and hence the loss of velocity is partly made up by increase in the amount of water present. Furthermore, the proportion of breadth to depth is greater in a mature than in a young river channel, and the increase in the number of threads of current running on the widened channel bed, where a large part of river transportation is effected, still further counteracts the effect of diminished velocity. But during these changes, the load of detritus to be carried is increasing, because the progressive dissection of the general land surface, characteristic of the advance of a normal cycle of erosion,

involves an expansion in the area of the valley-side slopes, from which the greater part of the detrital load of mature streams is supplied. Consequently, the decrease of over-abundant youthful carrying power and the increase of scanty youthful load will bring these two variable quantities to the balance that characterizes the graded condition of maturity. It by no means follows, however, that the maturity of the general land-surface, as measured by maximum dissection with maximum relief, is reached at the same time as the maturity of the larger rivers. Maturity of land-surface dissection is, in regions of moderate altitude, reached after, perhaps long after a mature grade is established in the main rivers. Therefore the load of such rivers will continue to increase even after graded courses are developed and after loss of surface water to underflow is well begun; and a result of this continued increase of load must be an aggradation of the already graded valley bottom, and a still further loss of surface flow to underflow in the thickened alluvium. The theoretical cause of aggradation of a mature valley floor was deduced a number of years ago; but the accompanying loss of surface water to underflow was then entirely overlooked.

Varying Equilibrium of a Graded River.—As a result of these various modifications, it appears that the variable quantities here involved in delicate interactions are continually falling out of one equilibrium and into another; but as the changes in their values are mere differentials of the values themselves, the changing equilibrium seems to us, in our brief period of observation, unchanging. As load increases, a part of the increase will be strewn along the floodplain, whereby the slope is raised, the velocity of the river is accelerated, and its carrying power increased sufficiently to sweep along the remainder of the load. As the floodplain is in this way given greater and greater depth, the surface flow is further reduced by loss to underflow, the carrying power is thereupon still more diminished, and still more of the load must be laid down; and so on, continuously. Hence, if no counterbalancing factors entered the problem, it would seem as if the floodplain ought to rise higher and higher and fill a greater and greater depth of the mature valley. But the variables here considered do not suffer large changes of value; the resulting readjustments of floodplain slope to carrying power and load are of small measure; and eventually certain counterbalancing factors must arise, particularly as the stronger relief of maturity weakens into the fading relief of old age; and no great depth of spontaneous aggradation in the mature valley need be expected.

Regain of Surface Flow in Old Age.—A very small counterbalancing factor may be found in the encroachment of the aggrading floodplain on the side slopes of the main valley, from which some of the

river load is supplied; but this is a second differential of the quantities of the first order, such as carrying power and load, and need not be considered in an equation where many stronger factors are of uncertain value. Two much more important counterbalancing factors, and indeed very effective ones, are found, first in the decrease in the quantity of load and in the refinement of its texture as the higher hills of maturity are worn down into the lower and lower hills of old age, and second in the accompanying decrease of "head" whereby underflow becomes sluggish and withdrawal from surface flow to underflow is checked. Thus an ageing river is given lighter and easier work to do, and has a larger and larger volume with which to do it—provided that regain of surface flow is not overcome by diminution of rainfall and increase of evaporation due to decrease of relief. The old river should therefore slowly wear down the aggraded floodplain of late maturity to a fainter slope and a less depth; and with diminution of depth the floodplain will hold less underflow. But however all this may be, these transcendental questions need not be pursued farther; they have already been carried beyond the need of the special inquiry here undertaken.

Underfit Rivers and Underground Waters.—If we now return to the examples of captured rivers given above, it becomes possible easily to explain the underfit meanders that they unexpectedly present by ascribing the loss of volume there implied to increase of deep percolation and of underflow in the widening and probably thickening alluvium of their aggraded valley floors. The Marne, a large branch of the Seine system, shows a moderately underfit habit of flow not far east of Paris; and it was for this river that Lehmann in the spring of 1912 offered his ingenious explanation; truly a far better explanation than any other yet proposed. More than that it may not be wise to say at present. Studies of underlying rocks and measurements of depth of alluvium along with estimates of volume of percolation and underflow in proportion to surface flow should be made in many cases of underfit rivers before a problem so complicated as this can be regarded as settled. But in the mean time it may be permissible to regard underfit rivers as, so far as they are concerned, confirming rather than contradicting the consequences that may be now deduced from the theory of the normal cycle of erosion.

Terminology of Meandering Valleys and Underfit Rivers.—Those who more or less fully accept the foregoing explanations for underfit rivers in incised meandering valleys will naturally wish to describe actual occurrences of such features in terms suggestive of their development. A general terminology for incised meandering valleys has been already indicated, in relation to successive stages of the cycle of erosion in which they are developed. Elongated and opened amphi-

theaters, undercut and slip-off spur-slopes, trimmed, sharpened and blunted spurs, and narrow and wide flood-plain scrolls are, as already suggested, helpful phrases. A fuller terminology is still needed to express the various patterns and dimensions of meanders, with respect to length of arc and radius of curvature. Open, half-turn, and dovetail meanders are illustrated in Figure 4, in examining which it should be remembered that river diagrams are always simpler than rivers. Radius of curvature can be most definitely expressed in feet or miles,

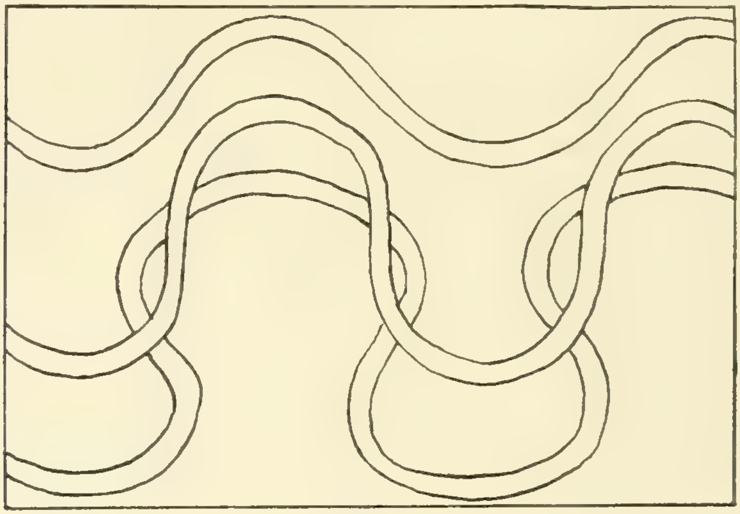

FIG. 4.

because such terms as short and long have no established meaning in this connection. The same is true regarding depth of valley incision and breadth of meander belt.

In describing underfit rivers in incised meandering valleys, the pattern and size of their meanders should be first stated in such terms as have been just proposed. Then the degree of their underfitness should be indicated by adjectives such as slight, moderate, striking and extreme, corresponding to the four underfit lines in Figure 5. The open meandering course of the upland river, before the incised valley as here drawn, was excavated is shown by pairs of broken lines drawn across the top of the axial slope of each spur at the upland level. The valley having been excavated, a slightly underfit river is shown by two parallel lines which fail by small amount to fit the smooth meanders of the valley; a moderately underfit river, by a single dotted line; a strikingly underfit stream by a broken line that meanders right and left on the meandering valley floor; an extremely underfit stream by a full line of minute crenulations. The lower Seine in Normandy shows a slight underfitness; the Meuse in northeastern France is an example of a moderately underfit river, and the Bar,

one of its beheaded tributaries, may be taken as the type of an extremely underfit stream. Stretches of both of these rivers, as shown on the Etat-major map of France, are reproduced in my Geographical Essays (pp. 595, 610). The term, underfit, will itself convey an explanatory suggestion to those who recognize that it is the sign of a peculiar relation of river and valley, whether they fully accept any explanation

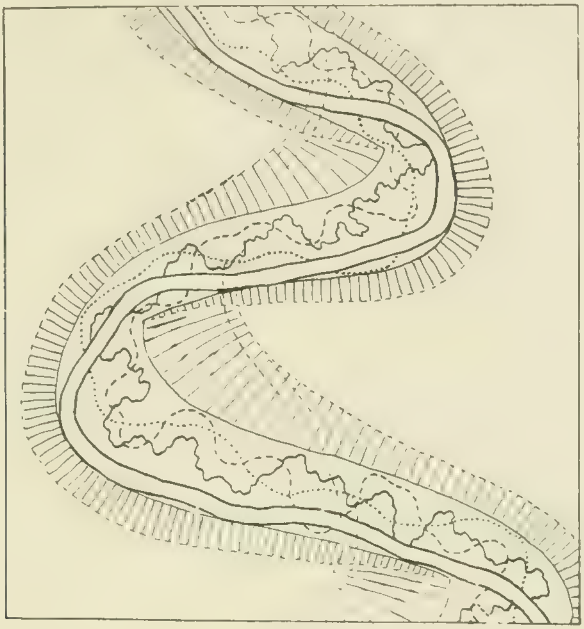

Fig. 5.

for the implied diminution of the river or not. When it is qualified, as slightly, moderately, strikingly or extremely, the explanatory suggestion of something peculiar is still more evident.

The Larger Lesson of this Problem.—There is a curious tendency on the part of certain conservative geographers to discredit the use of deduction in the treatment of geographical problems. Truly if deduction were the only mental faculty employed by a geographer, his results would be highly fanciful; but it argues a strange lack of imagination in the mind of a conservative for him to suppose so abundant a supply of imagination in the minds of other geographers, particularly of those who are concerned with the study of the solid land, that they fly off into the open space of pure deduction and abandon the safe footing of direct observation. Deduction is of no value in a subject like geography unless it is applied chiefly, perhaps exclusively, to drawing forth the consequences of a theory that has been invented to account for the inductively generalized facts of observation; and the deduced consequences of a theory have little value, except as they

lead one on to renewed observation, whereby the correctness of the deductions, and therewith the correctness of the theory from which they are deduced, may be tested. Those who suppose deduction to be otherwise used in geography thereby either disown or discredit their own methods of work. But all this is no novelty as a matter of principle, although it would seem, if one is to judge by the comments of certain writers, to be a novelty in their practice. Playfair made it all clear enough over a century ago, when he wrote as follows:

"The truth, indeed, is, that in physical inquiries, the work of theory and observation must go hand in hand, and ought to be carried on at the same time, more especially if the matter is very complicated, for there the clue of theory is necessary to direct the observer. Though a man may begin to observe without an hypothesis, he cannot continue long without seeing some general conclusion arise; and to this nascent theory it is his business to attend, because, by seeking either to verify or to disprove it, he is led to new experiments or new observations. He is also led to the very experiments and observations that are of the greatest importance, namely, to those *instantiæ crucis*, which are the *criteria* that naturally present themselves for the trial of every hypothesis. He is conducted to the places where the transitions of nature are most perceptible, and where the absence of former, or the presence of new circumstances, excludes the action of imaginary causes. By this correction of his first opinion, a new approximation is made to the truth; and by the repetition of the same process, certainty is finally obtained. Thus theory and observation mutually assist one another; and the spirit of system, against which there are so many and such just complaints, appears, nevertheless, as the animating principle of inductive investigation. The business of sound philosophy is not to extinguish this spirit, but to restrain and direct its efforts" (Illustrations of the Huttonian Theory, Edinburgh, 1802, pp. 524, 525).

The larger lesson of Lehmann's explanation for underfit rivers is that deduction ought to be more consciously and more thoroughly used in geographical investigation than it yet has been. The same larger lesson should be learned from the explanation of hanging lateral valleys over main valleys by means of glacial erosion. This explanation, foreshadowed by La Noë and De Margerie from evidence in the Alps (1888) and stated explicitly by Gannett (1898) in presence of the deep glacial trough of Lake Chelan, might have been deduced from established principles before any such trough was seen, inasmuch as Playfair had nearly a hundred years earlier pointed out the normal relation of branch and main valleys of ordinary erosion, and as every field geographer must have long been familiar with the relation of the beds of branch streams to those of main streams; the delay in the solution of the problem of glacial erosion was therefore largely due to the fact that no one had entered it with a conscious determination to study its deductive side as fully as its observational side. The larger lesson should again be learned from the explanation given by Wallace (1893) for the rayless lakes that so often occupy glaciated mountain valleys, the origin of which had been in debate between Ramsay and Lyell 30 years before; for Wallace's explanation, which accounts for such

lakes not by the warping but by the glacial overdeepening of preexistent normal valleys, might have been much earlier deduced in view of Dana's principle (1849) that coastal embayments must result from the partial submergence of a dissected land surface. And if errors are sometimes made in studies where deduction has had a part, as appears to be the case in the interpretation of the New England upland as an uplifted and maturely dissected peneplain, in the shaping of which marine abrasion was thought to have played no part, the evident lesson of such a mistake is, not that the effort to explain the origin of the uplands should not have been made, but that it should have been made more carefully, and that all of its observed and deduced elements should have been more closely scrutinized.

But in one sense, this exhortation is unnecessary; for it is perfectly clear that the geographers of the coming generation will give an increasing share of attention to the deductive side of their problems. A year's review of current geographical literature makes that evident.

Application of Lehmann's Principle to Regional Geography. —The object of physical geography is not to explain the past action of the processes by which the present state of the earth's surface has been brought about, but to describe the present state of the earth's surface in the best possible manner. It is, however, becoming increasingly common to attempt to describe the earth's present features by explaining their origin; that is by giving their history. Unfortunately this method of description frequently involves the discussion of so many conditions and processes of a former time, that the attention of both writer and reader is distracted by them from the present to the past, and writer and reader are to that measure metamorphosed from geographers into geologists. Some method of description should be invented whereby the geographical student, while still enjoying the vivifying influence that comes from an understanding of the origin of existing features, shall not have his attention seriously distracted from geographical to geological matters.

The best method yet found of securing this desirable end is to generalize and systematize the analytical explanation of present features through past processes. Instead of limiting an explanation to a single example of a general case, the explanation should be extended to cover all the phases of the case in their natural or evolutionary sequence; and then as an aid in gaining familiar acquaintance with all these phases in systematic order, appropriate names, usually in the form of nouns with qualifying adjectives, should be given to the type-concepts deduced for a certain number of stages in the sequence, so that the mere mention of a name will immediately and easily bring to mind the concept of all the detailed features that the name covers in their rationally developed and systematically associated relations. So long as the processes involved in an explanatory treatment remain

unfamiliar, and so long as the evolutionary sequence of the resulting features remains uncertain or obscure, the student cannot give his chief attention to the explained features, but must be distracted by trying to understand the explanation of the features. On the other hand, as soon as the explanatory treatment of a problem of this sort becomes clear, the deduced succession of evolved features and their proposed names will be easily apprehended and remembered; and thereafter the mere mention of a name will suffice to call up the corresponding type-concept and its meaning. Thus an explanatory description of an earth-feature, however many past conditions and processes it may involve, becomes a properly geographical description because it holds our attention closely to the present.

It is the principle of systematized explanation here involved that justifies the long and somewhat detailed treatment given above to the problem of meandering valleys and underfit rivers, as a practical aid in regional geography. For it is evident that the larger the mental equipment of a geographer, the better he can observe; and the enlargement of mental equipment is in no way more easily accomplished than by the careful and systematic deduction of mental types from theories that have been well established by thorough analytical investigation based on abundant observation.

The easy and effective use of an explanatory term in the geographical description of an underfit river in an incised meandering valley therefore involves not simply the explanation of the single case that the observer wishes to describe, but the thorough-going analysis of all the forms of the class to which the single observed case belongs, and then the establishment of a systematic series of type-concepts representing all these forms, and the adoption of appropriate names for a sufficient number of them, in the order of their evolutionary development. It is only after these two steps, the first analytic, the second systematic, have been carefully taken that an explanatory description can be used to best advantage. Evidently, if an observer who makes use of such a description is to be understood by his colleagues who have not seen what he has, he and they must have had the same training and must use the same terminology.

There is therefore a double responsibility, resting on geographical readers and writers alike, to analyze geographical problems and to systematize the results of analysis, as the essential means of making the best use of explanatory descriptions of geographical objects in regional studies. Many other problems offer as good, but no other problem offers a better opportunity for practice in this helpful preparation for the thorough treatment of regional geography than is found in the application of Lehmann's principle to the explanatory description of underfit rivers in incised meandering valleys.

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# THE SIGNIFICANCE OF EVAPORATION IN ANIMAL GEOGRAPHY

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CONTENTS



Introduction.—The geographic importance of an environmental factor is determined by its influence upon organisms. Environmental factors influence animal organisms in one of three ways. (a) *They may produce death.* (b) *They may modify structure or behavior.* (c) *They may stimulate migrating animals and cause them to turn back when an increase or decrease in the factor is encountered.* It has been demonstrated again and again that various isolated factors such as temperature, light, moisture, dryness, etc., may influence organisms in any or all of these three ways. Likewise it has been shown that various unanalyzed combinations of these factors produce death. Certain animals are killed by high temperature, intense light, much moisture, dryness, etc. The factors have been repeatedly shown to modify form, color, size and behavior of animals under experimental conditions. Further, it is well known that nearly all animals turn back upon encountering too high or too low temperatures or too weak or too strong light, as well as many other factors. Thus we may consider that a very large number of factors are known to affect organisms and to be of significance in animal geography.

*The Influence of Environmental Factors.*—Climatic conditions are so complex that animal and plant geographers have long sought some measurable index of climatic conditions. A few authors have held that food is a most important index. Others that moisture is the

controlling factor. Merriam has worked for many years on the assumption that total temperature above an arbitrary minimum, during the growing season, is the best index of the control climatic factors exert upon distribution.

*The Importance of Evaporation.*—It is the purpose of this paper to point out a large body of experimental work which shows conclusively that evaporation is the best index of conditions affecting warm blooded animals. A review of some experimental work by the writer, pointing to the same conclusion concerning cold blooded animals will also be presented.

The three ways (killing, modifying, producing avoiding reactions) in which the environment may influence organisms are not to be regarded as independent of one another or essentially different, because all result from interference with the internal life mechanism. The different results are dependent upon the character of the life mechanism in question and upon the intensity of the stimulation. Take as an example the effect of evaporation. Undoubtedly the same disturbance which causes the animals to turn back upon encountering air of high evaporating power results in death if it is continued and intensified. There is great difference in the time required to kill different animals from the same habitat, by evaporation and by other conditions, which indicates that distribution is far less a life and death matter than is commonly assumed. Reactions to conditions in experiment, the conditions selected and avoided, indicate the conditions suitable for the animals in nature. If such tests are made with reference to a sufficient number and combinations of conditions and at a number of periods in the life history, the reasons for the presence of animals in their environments may be expressed in terms of measured physical factors selected and avoided. These measures of the physical factors have almost invariably been found to represent the geographic conditions in the animal's environment. Tests of the reactions of animals, do not, to be sure, indicate everything that can be determined in the matter of relation to geographic conditions but there is little doubt that the particular type of reaction which results in turning back maintains animals in their usual environments wherever these end abruptly. Thus generally speaking, forest animals are probably restricted to forests, marine fishes are kept out of rivers, etc., by their activities merely because they turn back when the change in conditions is encountered. A large amount of data has been accumulated by students of animal behavior in the past few years, which shows that this works with a niceness of detail which is sufficient to support the view that animals are distributed very largely with reference to their behavior reactions. There are however doubtless cases in which this does not apply and where failure to survive

during some critical period, as for example during the egg stage, or the earliest stages outside of the egg, may be the cause of the absence of a species in question. But even here the results can rarely be ascribed to a single factor. It is likewise clear that the foundation for the explanation of distribution must be sought in experimental study of the effect of factors and combinations of factors upon organisms. Thus modern animal geography becomes *physiological animal geography* (Shelford '11).

Further as a result of selection of habitat or rather failure to leave the usual habitat and elimination of unadapted animals at sensitive periods, we may expect to find general physiological agreement among animals living habitually in similar geographic conditions. The writer has performed a series of experiments to determine the correctness of this general conclusion and the best means of measuring climatic conditions from the standpoint of modern animal geography.

EXPERIMENTAL RESULTS WITH EVAPORATION AND THE IMPORTANCE OF EXPERIMENTAL WORK TO ANIMAL GEOGRAPHY—*Methods Employed in Experiments.*—A series of experiments was performed by the writer (Shelford, '13) on frogs, salamanders, millipedes, spiders, insects. They were studied in glass tubes through which air of different evaporating powers was passed until the animals died. The reactions were tested in long narrow cages in which the rate of evaporation was different in the two ends and in the center. These different rates were produced by forcing air across the different thirds of the cage, moist air across one end third, ordinary air across the middle third, and dry, warm, or rapidly moving air across the remaining third. The rate of evaporation was measured by passing the air over Livingston porous cup atmometers at the same rate as across the cage. The behavior of the animals in the experimental cage was studied and compared with their behavior in an identical control cage which contained still air. The animals sometimes turned round in the control cage when no difference in the condition of the air existed, but on the average they turned back as often when headed in one direction as when headed in another. In the cages in which differences in evaporation were maintained they turned back much more often when headed toward one kind of air than when headed toward another. As a result, more time was spent in one half than in the other. If, for example, 70% of the time was spent in moist air, the animals often turned back 90% of the total turnings from the dry air. Thus the animals were negative to dry air and if we subtract the percentage of positiveness, namely 30% and 10% respectively, we have 40% and 80% respectively, which gives an average of 60% negative to dry air. This is the mode of determining the ratings given in Table I. The ratings represent negativeness or positiveness of reaction after the trials of

the opposite sign have been subtracted. Table I gives the rating of the species studied, obtained in this manner.

TABLE I.

Showing the rating of the different species studied when the turnings back from the modified air and per cent of time in the two halves of the experimental cages are regarded as of equal value. The ratings were obtained from the per cent of total turnings from the halves and from the per cent of time in the halves. The differences between the two per cents in each case were added and divided by 2. When the greatest number of turnings was from the end in which least time was spent the turnings and time are of the same sign (+ or —). Thus, the rating represents the degree of positiveness after the negative trials have been subtracted and vice versa.

| Species | Controls | | Experiments: Evap. Produced by Dryness | | Movement | | Temperature | | Average | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Number. | Rating. | No. Expts. | Rating. | No. Expts. | Rating. | No. Expts. | Rating. | No. Expts. | Rating. |
| From Beech woods: | | | | | | | | | | |
| Red-backed salamander (*Plethodon cinereus*) | 10 | ± 3.0 | 5 | —71 | 2 | —66 | 2 | —82 | 9 | —73 |
| Sticky salamander (*Plethodon glutinosus*) | 2 | ± 7.0 | 1 | —88 | 1 | —82 | .. | ..... | 2 | —85 |
| Ground beetle (*Pterostichus*) | 1 | ±11.0 | 1 | —72 | .. | ..... | .. | ..... | 1 | —72 |
| Wood frog (*Rana sylvatica*) | 19 | ± 1.5 | 5 | —68 | 2 | —80 | 2 | —69 | 9 | —72 |
| From Oak and Beech woods: | | | | | | | | | | |
| Millipede (*Fontaria corrugate*) | 10 | ± 6.0 | 6 | —43 | 4 | —55 | 2 | —83 | 12 | —60 |
| Widely distributed (collected from sand dunes): | | | | | | | | | | |
| Toad (*Bufo lentiginosa*) | 9 | ± 8.0 | 4 | —46 | 2 | —23 | 3 | —27 | 9 | —32 |
| From dry sand dunes: | | | | | | | | | | |
| Digger wasp (*Microbembex*) | 6 | ± 1.3 | 6 | + 6 | .. | ..... | .. | ..... | 6 | + 6 |
| Spider (*Geolycosa* sp.) | 7 | ±10.0 | 4 | +18 | 2 | +16 | 2 | +12 | 8 | +15 |

*The Relation of Evaporation Effects to Integuments.*—The animals killed by rapid evaporation fall into two distinct groups: (a) those dying with an evaporation varying from 0.07 to 5.40 c.c. after an exposure varying from five to one hundred and sixty-five minutes, and (b) those dying with an evaporation of 31.0 to 42.0 c.c. after an exposure of from 1,300 to 2,200 minutes. The first group was made up of soft-skinned amphibians, the second of chitin-covered Arthropods. Even though the Arthropods were much smaller and hence had more surface per volume (Hill, '06, p. 267), they lived from eight to four hundred and fifty times as long as the amphibians. In general, there was only a rough relation between survival time and reaction among animals *with similar integuments.* Of the amphib-

ians the red backed salamanders died in dry air in 58 min. and sticky salamanders in 87 min. They are rated respectively at — 72 and — 85; the toad died in 160 min. and is rated at — 32. Of the chitin-covered animals the ground beetle is rated at — 72 (single expt.) and died in 1,300 min.; the millipede at — 60, died in 1,830 min.; the spider rated at + 15, died in 2,200 min.

*Evaporation and Habitat Groups.*—The ratings given in Table I clearly fall into two groups which are habitat groups. The salamanders, millipedes and ground beetles (— 60 to — 85) were taken from the surface of the ground under the leaves in a primeval beech forest; the spiders and wasps (+ 6 to + 18) are regular residents of the driest open sand areas. The toad is an incidental resident of the sand area. A relation exists between habitat and survival time but it is confined to animals with similar integuments. No such relation exists when one entire habitat group is compared with the other habitat group. Omitting the toad we find that the regular breeding residents of the two habitats (beech woods and open dunes) differ in kind and degree of reaction in a manner comparable with the difference in physical conditions of the habitats (Shelford, '12b).

A further comparison of the different species given in the table shows important relations to vertical conditions of forest developmental stages (Yapp, '09; Sherff, '12; Shelford, '12a; Fuller, '12), evaporation being least in the ground and at the forest floor, increasing rapidly vertically. The wood-frog spends much of its time during the day hopping about the forest floor. The red-backed salamander lives more of the time beneath the leaves and is clearly more sensitive to evaporation. The sticky salamander occurs in numbers in the beech woods proper only in moist seasons. Ordinarily it is confined to ravines where Fuller ('12) found the average evaporation per day for the season to be 1.5 c.c. less than at the surface of the forest proper. Since the sticky salamander occurs in moister situations than does the red-backed the difference in the sensitiveness of the two species is related to habitat. The habits of the ground beetles are not well known; the species studied seem to be regular inhabitants of moist woods. The millipedes, while common in beech woods, are still more common in oak-hickory woods where evaporation is 1 c.c. per day greater. The millipedes are less sensitive to evaporation than the ground beetles. The reaction of the spiders and wasps is in accord with the high rate of evaporation in the sand dunes which they normally inhabit.

SUMMARY OF GENERAL RESULTS—*The Experimental Results of the Writer.*—The animals studied reacted to differences in evaporation, whether they were produced by *movement, dryness* or *heat.* Forest (low evaporation) animals turn away from air of high evaporating

power, and show a preference for air of low evaporating power. Sand dune (high evaporation) animals turn away from moist air and show a slight preference for air of high evaporating power. Thus the *type of reaction is definitely related to the usual habitat of the animals.* Furthermore *all* the animals from a given habitat subjected to the tests, were found to be in *agreement* in reaction though there was *no general agreement* in the length of *time required to kill* them by desiccation.

*Experimental Results of Other Investigators.*—The work on the physiological effect of evaporation from the bodies of animals has been confined chiefly to the warm-blooded domestic animals and man. The loss of water from the human body was early noticed by Hippocrates and by Galen. Chalmers (1776), Seguin and Lavoisier (1789-90), Abernethy (1793), and Sharling ('42) all appear to have noted water output from the body or lungs. Tiedemann ('36) described the symptoms of great thirst experienced by travelers in the desert. The first thirst is followed by dryness and smarting of the throat; next the respiratory action is increased and later long deep breaths alternate with hiccoughs; hoarseness occurs and is followed by loss of speech; the pulse is quickened; the skin becomes dry; the muscles become weak and a feeling of great fatigue ensues with staggering and labored movements. The thirst then becomes maddening and loss of consciousness usually follows.

Some of the early experiments in physiology were water starvation experiments on birds and mammals. Nothwang ('92) summarizes this early literature. He states, on the basis of his own investigations, that fat animals resist lack of water better than those without fat. Weyrich ('62) studied the loss of water from the body and confirmed the work of earlier writers; Reinhard ('69) found that the water loss was dependent upon *temperature, humidity, wind velocity,* and *pressure.* These factors control evaporation (see also Falck, '72; Erismann, '75). Rubner ('90b, '90c) found that the rate of evaporation was of much importance in connection with the factors pointed out by Reinhard, in determining the rate of *metabolism*, and general heat *regulation economy* in men and dogs, and with Cramer ('94), noted the effect of hair covering and of sunlight upon water loss and heat regulation. Schierbeck ('93) carried on similar studies and (in '95) stated that evaporation should be measured.

Wolpert ('98, '99, '02a and '02b) studied the effect of moisture on laborers, the effect of oiling the skin on water loss, the influences of evaporation upon the skin, and the influence of air movement upon water loss and carbon dioxide production confirming the results of others and adding further details. Up to 25° C., $CO_2$ production is increased by air movements; at higher temperatures, decreased. Hal-

dane ('05) worked upon the effect of high temperatures on man and found that the discomfort was due to a *rise of body temperature.* The ill-effects were partially prevented if the air was kept moving, thus increasing the evaporation.

Hill ('06) summarizes the important work on the subject of water relations and heat regulation and adds the results of his own investigations. The heat regulating power of a mouse fails at 24°-25° C. (p. 269) in a saturated atmosphere, due to rapid loss of heat, and the animal dies from cooling. In man it fails at 29° C. in a saturated atmosphere and if he is active and clothed, he suffers from overheating. At 37° and in the absence of clothing, any exertion is practically impossible. In a dry air a man may sit for a time at 100° C. Sutton ('08) states that heat stroke occurs only in a very moist atmosphere (see also Osborne, '10). Aron ('11), working on men and monkeys, found that death from exposure to the tropical sun in the Philippines was not due to any effect of the tropical light (Woodruff, '05; Caskellani and Chalmers, '10), as had commonly been supposed, but to an overheating of the body. This could be prevented by shade or by air currents which increased the evaporation. In conclusion he states: "My experiments demonstrate the enormous physiological and hygienic importance of ample water evaporation in the tropics."

All animals produce some water through the oxidation of the hydrogen in their food. According to Atwater (Hill, '06) man produces about one-third to one-fourth of the amount of water which he gives off through the skin and lungs. Mathews ('13) called attention to this fact in connection with the adaptation of reptiles to desert conditions. Berger ('07) studied the water relations of the meal worm (*Tenebrio molitor*) when kept in dry air and fed on bran which had been dried at 105° C. He considered that the animals were in essentially absolute dryness. Here they lived for weeks but lost weight. He found, however, that the per cent of water in the animals remained practically the same until after death and came to the conclusion that the insect larvae could not use their food to produce water and so the living substance itself was used. No doubt the food taken produced water, but this was not sufficient in quantity. The most important fact brought out was that the per cent of water remained about the same in spite of the extreme dryness and rapid loss of moisture. Pernice and Scagliosi ('95) worked upon fowls which had died of water starvation. They came to the conclusion that the possible water fluctuation of the animal tissues is very small and whenever a cell's water content passes a certain limit, death ensues. Hill ('06) states that with a loss of ten per cent of his weight in water, a man usually dies.

Many animals, such as reptiles, which are dominant in deserts possess thick skins which prevent the loss of water by evaporation. Others, such as reptiles and birds, lose very little water in the form of nitrogenous waste, such waste materials being cast from the body in a nearly dry state. No mechanism to prevent loss of water exists in the common frog; its water demand is supplied through the skin. Durig ('01) found that the common European frog died if the loss of water was rapid when 15 per cent of the frog's weight was withdrawn. If the drying was slow the frogs could lose 30 to 39 per cent of their weight in water without dying. When the weight was reduced to 61 per cent the blood corpuscle count was increased to two and one-half times the normal.

General Summary of Relations to Evaporation and the Reasons for its Determination.—On the basis of the experimental work cited, the reasons for the necessity of determining evaporation in connection with the effects of temperature, moisture, wind movement, and insolation may be summarized as follows:

a. The total effect of air temperature, pressure, relative humidity, and average wind velocity upon a free water surface is expressed by the amount of water evaporated (Hann, p. 72).

b. The same factors have been shown to determine the amount of evaporation from the bodies of organisms (Reinhard '69).

c. Metabolism results in heat and the temperature of the bodies of animals, both warm and cold blooded, is nearly always higher than the surrounding medium, at least during activity (Schaeffer, Vol. I, p. 785). The surrounding conditions may be stated as usually acting on metabolism, etc., as follows: (a) A moist cold atmosphere (very low evaporation) causes body temperature to fall more rapidly than a dry cold one at the same temperature because of the more rapid conduction of heat. Such a fall in temperature *decreases* metabolism of *cold blooded* animals and *increases metabolism* of warm blooded animals within their capacity for heat regulation. In a dry cold atmosphere the heat loss is less pronounced because of the less rapid conduction of heat. (b) In a dry warm atmosphere (high evaporation) rapid evaporation keeps down the peripheral temperature, and prevents death from overheating and destructive metabolism in cold blooded animals, and makes possible body temperature regulation and thus prevents heat stroke and death in warm blooded animals. In a moist warm atmosphere, death and heat stroke occur because of lack of evaporation and lack of peripheral cooling in the case of warm blooded animals, even when the surrounding temperature is at or below the normal body temperature. (c) Wind movement (which increases evaporation) increases radiation of body heat and of heat due to insolation. It increases evaporation and thus further

cools the body, increasing the metabolism of warm blooded animals and decreasing it in cold blooded animals. (d) Decreased pressure increases evaporation and radiation, both of which lower the temperature of animal bodies and influence metabolism, as stated under (c).

d. Conditions which withdraw water from organisms (evaporation as influenced by various factors) influence irritability, activity, and length of life history. Thus Hennings found that low humidity increased insect metabolism and Sanderson found that in dry air the optimum temperature of the growth of insects was lower than in moist air. Thus there are no doubt many exceptions to the usual rules as given under c.

The work summarized above, shows that there is an excellent experimental basis for a statement of the factors controlling the distribution of animals. It is evident that *temperature* data have little significance unless the humidity is known. Neither of these can be interpreted without a knowledge of the pressure, insolation and wind movement. The experimental foundation for the consideration of all these factors in combination, in terms of evaporation, was laid down by Reinhard ('69) and Rubner ('90). The best method of expressing them climatologically was clearly stated by Schierbeck ('95) as the amount of water evaporated. His conclusion is stated as follows: "Bei der Beurtheilung des Einflusses eines Klimas auf die Wärmeregulirung des Organismus und bei der Beurtheilung der austrockenden Wirkung desselben sowohl auf den Organismus als auf leblose Gegenstände ist das Haupt gewicht auf die Geswindigkeit der Verdampfung zu legen." This does not mean that records of the separate factors involved, namely, temperature, pressure, humidity, insolation, wind movement, etc., should not be made, but rather that the best expression of their combined action is the rate of evaporation. The work of Sanderson ('10) shows that moisture is important in insects in connection with temperature. The striking similarity of reaction and survival time to air of similar rates of evaporation on the part of the animals regardless of whether due to *dryness, heat* or *velocity* speaks very strongly for the measure of evaporation in connection with cold blooded animals.

It is a noteworthy fact that the relation of warm blooded animals to climatic factors had been observed (Livingstone, '58) and experimentally studied (Reinhard, '69) (Rubner, '90) before Merriam ('90, '94, '98) published his theory of temperature control. (See also Swain, '05; Craig, '08; Roosevelt, '10; Mathews, '13.) He made a most important contribution in his emphasis of the breeding period. However, Sanderson ('10) has shown that total temperature above an arbitrary minimum is *not* a good index of conditions affecting the growth of insects. There is no good experimental evidence to indi-

cate that such a total temperature is any more significant than total pressure, total sunshine, total wind movement, or (Walker, '03) total humidity. Temperature control has worked in the mapping of distribution just as any theory whatsoever will work for some species, be it concerned with a wandering pole or an Atlantis. The facts and causes of distribution are much more complex than temperature control assumes.

Finally in seeking convenient indices of geographic conditions, we must not overlook the fact that all environmental relations last throughout complete annual cycles and entire life histories. Sometimes conditions during periods when most organisms are inactive are important, for example *winter temperatures* wholly or partially control a large number of plants and animals (Sanderson '08, Shelford '13, p. 177). In all cases indices of the controlling factors are *not* to be found in the total of the selected factor or combination of factors during the entire year or during one particular season, but rather *in the peculiar character of the annual rhythm.*

It should further be noted that meteorological data of any sort, evaporation, insolation, temperature, rainfall, etc., are obtained in a manner which often makes their application to the distribution of most animals impracticable. Such records are taken under conditions of exposure which do not usually represent the animal habitats of the region. Thus in a forested region data should be obtained *in the forest,* in desert regions with full *exposure to the elements.* In the study of both organisms and environment, we have made only a small beginning and the work to date even if fully brought together gives us only a guide to future investigation.

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# COASTAL PLAINS AND BLOCK MOUNTAINS IN JAPAN

SUMNER W. CUSHING

CONTENTS



INTRODUCTION.—Opportunity to do the work on which this paper is based was afforded the writer in the spring of 1911, while returning from carrying on geographical research work in India as a Sheldon Fellow of Harvard University. The work was done under the inspirational suggestion of Professor W. M. Davis.

For the geographer, a pleasing approach to Japan is through the far-famed Inland Sea. The route runs from the west gate, on the north side of which stands Shimonoseki—the Gibraltar of that oriental Mediterranean—some 250 miles to Kobe, at the east end of the Inland Sea, where his ocean steamer finds it profitable to make the first stop. Throughout this long stretch, if he is fortunate in weather and if the steamer's schedule covers most of this route in daylight, the geographer will receive a lesson of the highest interest, and at the same time be struck by all those more aesthetic appeals of color, form, and life, for which this picturesque inland sea is noted. Most of the numerous islands encountered are hilly or mountainous and seem to be of volcanic origin. Some are typical of normal drowned shorelines. They are so little forested that even from the passing steamer

it is easy to identify a great variety of land forms in lava and cinders showing many stages of erosion, largely as a result of marine agents. Further, some islands having been slightly elevated exhibit miniature coastal plains about re-entrant margins, while others show the effects of depression in embayed coast lines. From the steamer the varied activities of the farmer-fisher folk can be observed along the terraced slopes, in their unique fishing boats, and even in the villages that crowd the shores in some of the narrows.

At Kobe the western margin of the 20th century Japan is reached. This progressive industrial and commercial region extends to the east along the south coast of Hondo, the principal island, as far as Tokyo, and includes five other leading cities of the Empire, Kyoto, Osaka, Nagoya, Shizuoka, and Yokohama. Location on the south of the island on the route of steamers between the west coast of North America and the east coast of Asia, has meant much in their development. But a larger factor has been the plains between the mountains and the sea which constitute the setting of each. In a country so mountainous that its arable land is less than fifteen per cent. of the total surface, it is to be expected that what limited plains there are will exert dominant influences in the development of centers of population, even when the country approaches the industrial stage of development. This paper treats of these plains, the block mountains that stand in relation of oldlands to them, and their geographical influences.

Outline of Problem.—A glance at the map, Fig. 1, will reveal a series of five bays on the south of the island of Hondo all opening toward the south-southwest, all of nearly the same size, 20 by 40 miles, and of very nearly the same pattern. These are from west to east, the bays of Osaka, Owari, Suruga, Sagami, and Tokyo. Further, it will be observed that each is bordered by a plain that broadens at the bay head on the north and extends into the interior. An exception to this is in relation to Suruga bay where Fujiyama, the great volcano, and Ashitakayama, a composite volcano, have been built up in the area that corresponds to the interior plain in the others. Again, in each region the plains are backed by mountain ranges that extend from north-northeast to south-southwest in sympathy with the longer axes of the bays. Between the consecutive members of the series the region is usually mountainous. Lastly, in almost all of the units there are three centers of population each with distinct activities, one a port, another a manufacturing center, and the third a collective point and trading center for the interior plain: such as Kobe, Osaka, and Kyoto in the Osaka bay district, and Yokohama, Tokyo, and Utsunomiya in the Tokyo bay district.

These strikingly similar conditions and responses hint at similar origins. Studies in the field seem to show, as indicated in Fig. 2b, that

the initial bays resulted from down-faulting of blocks of a peneplained surface, along lines extending north-northeast—south-southwest, and at right angles thereto; that the plains have resulted from two slight general uplifts of the whole region, perhaps of a slanting character, more at the north, little or none at the south, after the basins formed by the depressed blocks had long received the waste from the adjacent

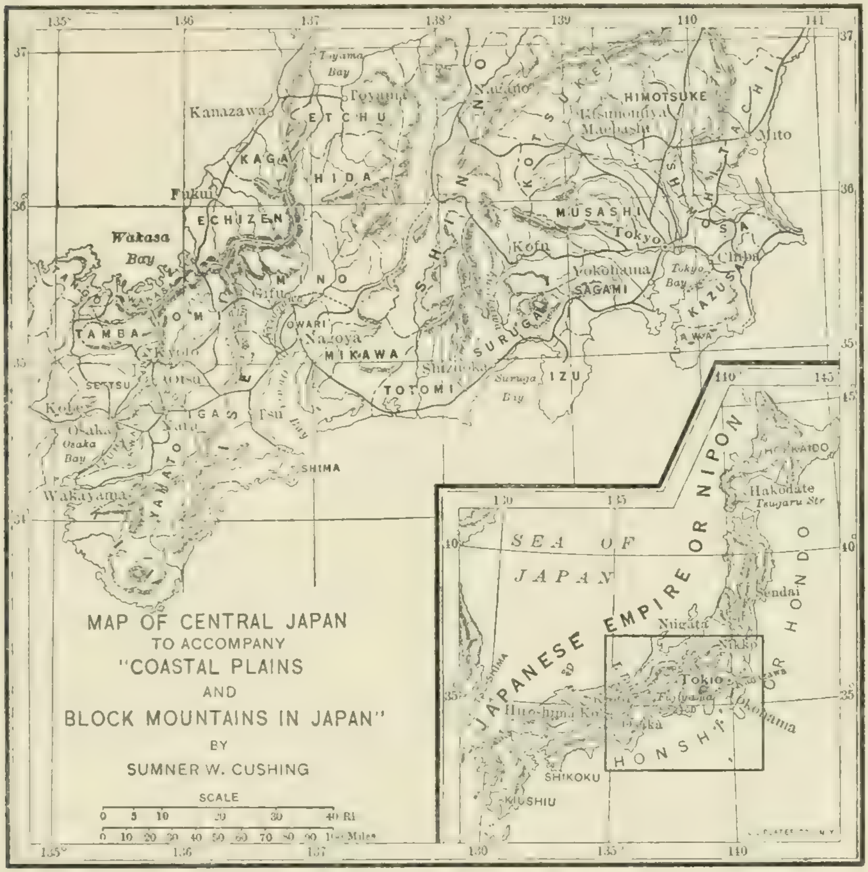


FIG. 1.—General map of area treated in this paper.

mountains. Or, to present the region in the vicinity of the southern shore of Central Japan completely yet concisely, it appears to have been in remote times a region of disordered crystalline structures that was reduced nearly to sea level, and faulted along north-northeast—south-southwest lines and at right angles thereto, into crustal blocks which were in general uplifted and tilted to form block mountains—even now in their youth, but in a few cases depressed to form bays and in one case to form a lake basin. Since then the region has received two slight general uplifts:—the first initiating a coastal plain, at the margins of the bays, that suffered severe marine, as well as

normal erosion—the former aided by a slight depression; the second uplift initiating another coastal plain, which is still young, bordering the former, the mature coastal plain, and articulating with it in the broad valleys.

Osaka Bay District.—Since this district was more extensively investigated by the writer than the others, it is here selected to illustrate the general features shown by all the districts, as well as a few characteristics not seen elsewhere.

Physiography—*The Block Mountains.*—The mountains are of complicated structure, from much inclined, little-folded sandstones to distorted metamorphics and huge masses of intrusive igneous rocks. West of Osaka bay the mountains are of granite. On the east they are of loosely consolidated sandstones that strike northeast and dip 50 degrees to the southeast. Farther to the east they are backed by granite mountains to which they stand as foothills. Most of them are grouped in ranges that run rudely parallel from north-northeast to south-southwest, as shown in Fig. 2. A few others extend roughly at right angles to these. Each range is characterized by a gentle slope in one direction and a steep slope in the opposite, by a fairly even crest line (if the volcanoes that some support are ignored), and in many cases, by the striking alignment of the triangular facets at the spur ends of the steep slope, in a manner shown in Fig. 3. These features seem to indicate that the mountains are carved blocks, and that they are in the early stages of post-faulting dissection. This theory as to the origin is further supported by evidence that faulting has been continued into comparatively recent times, as is indicated in the updragged attitude of the strata of some of the mature coastal plains and fans at their inner margin close to the base of the mountain face (found especially in the Owari bay district), as if a recent movement along the fault plane had carried the slightly inclined layers into a nearly perpendicular position. The close association of numerous earthquakes with these mountain bases is in sympathy with this theory. Official investigations seem to indicate that of late years at least, the east portion of southern Hondo—the general area under consideration—has been more subject to earthquakes than any other part of the Empire. In Tokyo the average yearly number of shocks, exclusive of minor vibrations, is nearly a hundred. European residents at Kobe, a city near the mountain base on the west side of Osaka Bay, find it necessary to return home every few years to recuperate, so affected are their nervous systems by the numerous earthquakes and tremors. Fig. 2 shows that according to the theory, Osaka lies over a fault plane. On October 28, 1891, it was the center of a great earthquake that destroyed nearly 10,000 lives. This was the greatest of many recent shocks.

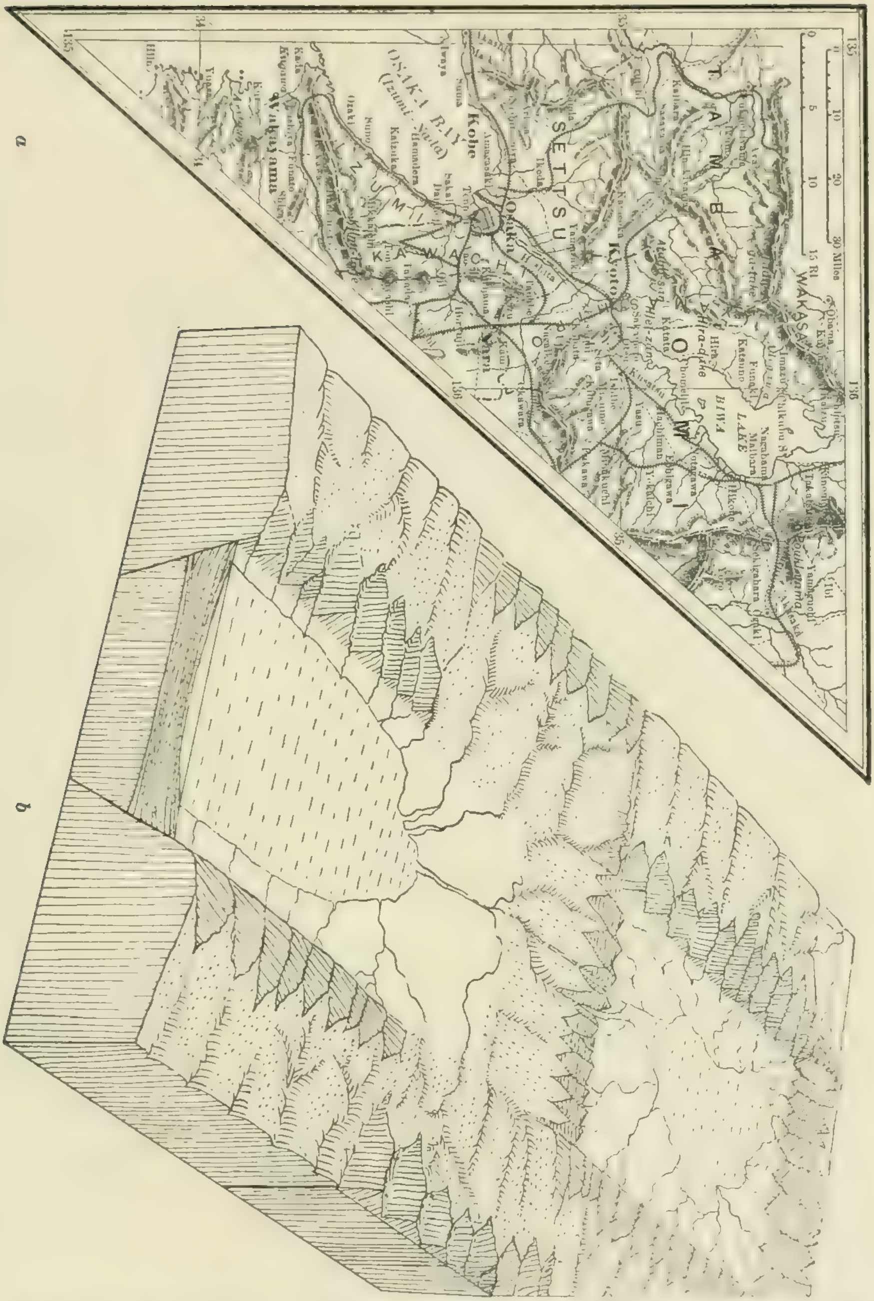

FIG. 2 a and b.—General map and block diagram of Lake Biwa district. No attempt is made to show the numerous volcanoes or to distinguish the mature from the young coastal plain.

The steep slopes of the block mountains face in various directions according to the manner in which the blocks were tilted as they were uplifted. Adjacent blocks sometimes show the steep slopes facing in opposite directions, as is illustrated in Fig. 2b, west and northwest of Osaka bay. Under such a condition the range lacks continuity. From the base of the steep slopes the block edges present truly mountainous aspects because of the rapid ascent and the ruggedness into which the numerous swift-flowing streams have carved the most exposed

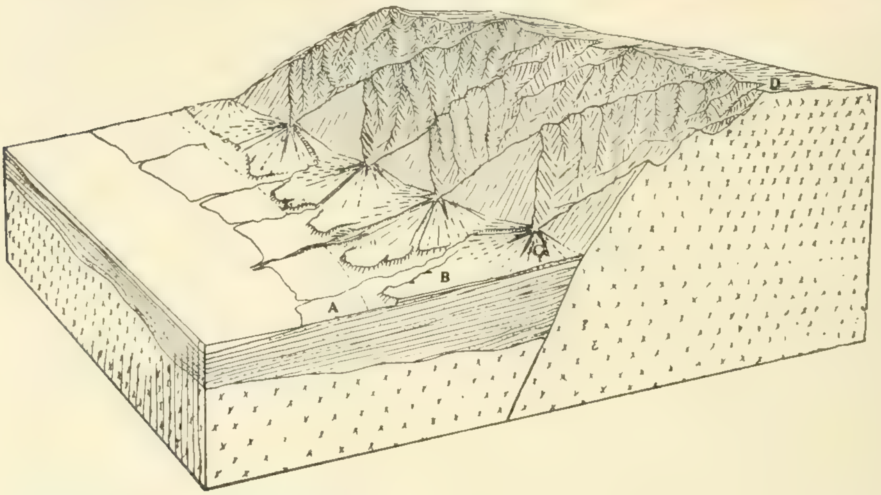


FIG. 3.—Block diagram of the young coastal plain (A), mature coastal plain (B), dissected fans (C), and fault block mountains (D), northeast of Kobe in the Osaka Bay district.

edges, as in Pl. VIIb. From the base of the gentle slope the blocks show no parts rising conspicuously into peaks, as shown in Fig. 6, except those made by volcanic cones.

The evenness of the land in the interstream spaces on the gentle slope shows that the region had been carried well along toward old age before it was faulted and brought into its present elevated and tilted attitude. The mountain growth must have been vigorous since there are few, if any, antecedent streams. The drainage is of the simple consequent type.

The oldlands of districts other than Osaka bay and the west side of Owari bay were only superficially examined, so their classification as block mountains, although supported by evidence that was gathered, is made tentatively.

*The Plains.*—The plains of this section are of two types: one a combination of a mature and a young coastal plain extending around the bay, that is typical of all the south bays as has been pointed out above; the other, a lake plain at the northeast about Lake Biwa, as shown in the map and the block diagram of Fig. 2. The bay and

the lake occupy basins having such relations to each other and to the block mountains as to suggest that their existence is due to the depression of crustal blocks; the depression of one block developing an arm of the sea because of its relation to the former sea margin, the other making an inland basin holding a lake.

*The Coastal Plains.*—These plains average only two and a half miles in width, as in Pl. IIa, on the northwestern side of Osaka bay. The young coastal plain takes up about half of this width, as shown in Fig. 3. It is made up of well stratified fine gravels and coarse sands, and has on its outer margin a number of small deltas of finer material. Back of it at the northwest is the mature coastal plain. It is in the form of a series of terrace-like spurs, isolated from one another by extended consequent valleys, and having their upland surfaces at the same general level. The seaward margins of the spurs are elevated sea cliffs, and the lateral margins, valley slopes to the extended consequent rivers, as shown in Pl. Va. Upon the northwest parts of the mature coastal plain are large fans that have been built up by the short swift rivers emerging from the young valleys of the steep slope of the block mountains which constitute the oldland of the plains, as in Pl. VIa. The fans are nearly as conspicuous in size as the spurs of the mature coastal plain, as sketched in Fig. 3. They are now in an advanced stage of dissection. It seems probable that the uplift which initiated the young coastal plain gave the rivers the incentive to bring about this dissection.

The plains gradually widen from southwest to northeast, as shown in Figs. 2 and 3. One cause of this is that the larger rivers emptied more sediment into the head of the bay than along the flanks and so built a very gently sloping bay floor previous to elevation. Again, the northeastern plains being more protected from sea attack, the rivers have added deltas to their margins, whereas in the southwest, beyond the area diagrammed, marine erosion has been so vigorous as to cut away the plains quite to the base of the mountains. Nearer Kobe the mature coastal plain shows by its narrowness and elevated sea cliffs that it suffered almost complete annihilation previous to the last uplift, as indicated in the distant part of Fig. 3.

Just before the rivers cross the line separating the mountains from the plains their courses in many cases are interrupted by falls, as is shown in Fig. 4 and Pl. X. These seem to owe their existence to the recent uplift. Other falls, seemingly those associated with the uplift that brought into being the now mature plain, exist a little higher up in the courses. Thus back of Kobe there is the Men-daki, or "Female Fall," 43 feet high, and a little higher up the On-daki, or "Male Fall," 82 feet high. In the higher courses of the rivers are falls which generally characterize young rivers that flow over vary-

ing structures. The youthfulness of the valleys suggests recent re-entrenchment due to uplift.

On the southeastern side of Osaka bay the plains are wider and more varied in their relations. In the central part, for instance, the mature coastal plain reaches quite to the sea and terminates in a sea cliff that is being rapidly eroded, as is evident in Pl. IVa. This forces the railroad to trench or tunnel through the interfluves of the mature

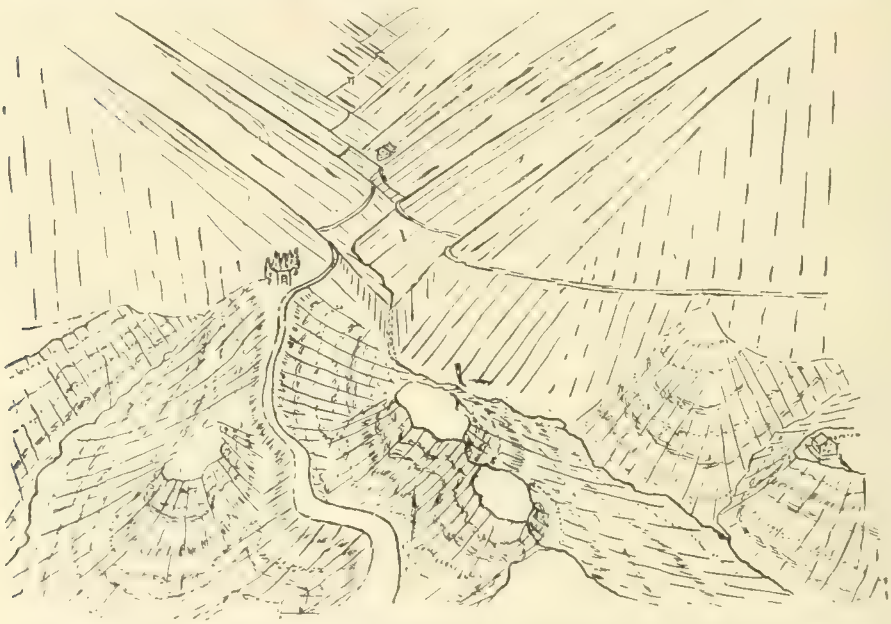

Fig. 4.—At the apex of a much dissected fan looking up an extended consequent valley to the interlocking spurs of the oldland valley, showing a Shinto shrine at the fall line.

coastal plain, while roads along the coast have to climb over them. The sea cliffs permit porcelain manufacturers easily to appropriate the clay from the strata of the mature coastal plain, and carry it away by water, as shown in Pl. IVa.

Another variation is found in the northeast part of this side of the bay where the coastal plains have for the oldland a gently inclined back of a tilted block, as shown in general in Fig. 2b, and in detail in Fig. 6 and Pl. IVb. Here the contrast between the plains and oldland is not so striking in topography, but close examination reveals strong differences in structure, minuteness of dissection, and soil, resulting in very unlike vegetation responses.

Still another variation found on this side of the bay is a general absence of fans at the inner margin. Typical conditions are shown in Fig. 5 and Pl. IIIa. Normal flood plains are found at the lowest level, bordered by valley slopes that lead to the young coastal plain surface

which here reaches quite to the oldland mountain base. The young coastal plain is in turn bordered by longer slopes that lead to the mature coastal plain surface. Lack of fans seems to be the result of weaker oldland structures, as if the rivers were able to keep their valleys graded between the oldland and the plains as the mountain block rose.

*Lake Biwa Plain.*—The Japanese have great confidence in the legend that Lake Biwa was formed in the year 286 B. C., as the result of a

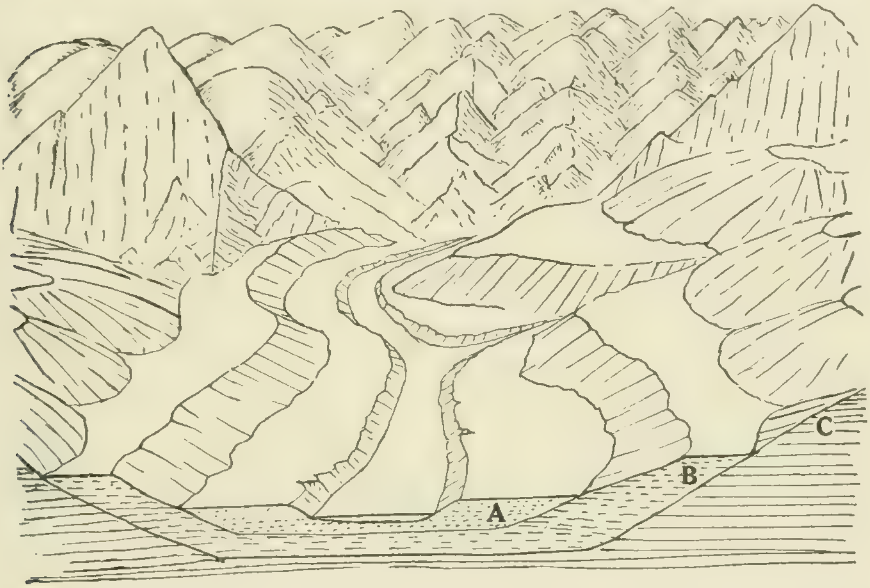


FIG. 5.—In the southeast part of the Osaka bay section, near the inner margin of the coastal plains, looking toward the oldland along the valley of an extended consequent river. A, Present floor plain; B, Young coastal plain; C, Mature coastal plain.

great earthquake. This is not inconsistent with the theory here advanced to account for the basin of the lake. It can be readily seen that if the basin, formed by the depression of a crustal block, had been drained by the cutting down of the outlet and raising its floor by deposition of sediment, the drainage could have been again blocked and the lake reformed by a slight upward movement of the south crustal block, or by farther depression of the basin block, either of which would have been accompanied by an earthquake. However, the legend is not taken as the best support to the theory. That is found principally in the characteristics of the mountain ranges surrounding the basin, which are like those that have been already pointed out in relation to Osaka bay at the south, and which are shown diagrammatically in Fig. 2. If the lake basin be due to the depression of a crustal block, it is probable that the surface of the block dips

toward the west, since on that side the lake reaches nearly to the mountain base at several places, whereas on the east a wide plain intervenes between the lake and the mountains, suggesting shallower waters that allowed the filling of the basin to lake level to proceed more rapidly. From the center of the lake it is observed how completely the basin is surrounded with mountains and how even is the sky line, except where volcanic cones raise their isolated symmetrical summits to greater heights. The even sky line can well be explained on the basis that the blocks which were elevated to form the enclosing mountains, were in prefaulting times reduced to a peneplain.

The plain itself is made up of laterally coalescing fans at the base of the mountain margin and is a typical lacustrine coastal plain around the lake. The surface is interrupted here and there by hills of various origin. Those about the margin seem to be dissected splinters of the upthrown blocks or of later volcanic origin, while nearer the lake there are some that seem to be tops of monadnocks of the depressed peneplained block or small volcanic cones. Some of the hills form islands in the lake.

Life Responses—*Shallow Bay Bordering a Young Coastal Plain.*—There are no natural harbors for large vessels in the bays on the south of Hondo because of the gently sloping bay floor associated with the young coastal plain. Small sailing boats find harbor space back of spits made by currents in front of river mouths, as is shown in Pl XIa. Large steamers anchor offshore and communicate with the land for freight and passengers by means of lighters. The site of Kobe was selected in 1868 by foreigners because of a cape just southwest, Wada-no-Misaki, an elevated sand spit, developed before elevation by a strong southwest current working upon offshore sands. This furnishes some protection for steamers riding at anchor. In 1907 there was started a ten years' campaign of dredging and wharfing Kobe's water front in order to overcome the handicap of a gently sloping bay floor and to let the largest vessels receive and deliver goods and passengers with convenience. It is interesting to note that Yokohama, the other port that shares first rank in the empire for value of imports and exports almost equally with Kobe, has exactly the same physiographic setting and has solved its difficulties in somewhat the same way that Kobe is now attempting.

It would seem reasonable to expect that the two leading ports of Japan would be on two of the scores of excellent natural harbors of the Empire, but instead Kobe and Yokohama have grown in spite of their location on bays too large to be considered safe harbors, and too shallow about the margins to facilitate communication with the shore. The extensive plains in the immediate back country of each seem to have forced their rapid growth, while remote deep bays, poten-

tially fine harbors for commerce, but without contributing back-land plains, serve to shelter only fishing craft, junks, or a few coastwise steamers.

The gently sloping bay floor bordering the young coastal plain is taken advantage of by the Japanese in fishing. They drop a net into the bay a short distance from shore. Floaters hold one edge at the surface of the water and the width is great enough to allow the other edge to reach quite to the bottom. The rope-ends of the net are taken ashore and as it is pulled in it makes an effective trap for the fish that frequent the shallow waters. It is obvious how futile this method would be along a deep, rock-bound, ledge-strewn, coast.

Near the head of the bay where the margin of the sea floor slopes very gently, the coast dwellers make the sea contribute a share to their supply of vegetable foods. Rows of tree limbs set out in the shallow water serve as inviting areas of attachment for seaweeds. Only the esculent varieties are allowed to grow—those little deserving the title "weeds." They are regularly gathered by hand at low tide.

*Young Coastal Plain* — **High Density of Population and Vegetation.**— It is difficult for a dweller in a new country like the United States to understand what it means thoroughly to utilize the land surface. A visit to the young coastal plains of the various districts offers a striking object lesson in land economy. The Tokyo plain supports about six million people (calculated from the census of 1908) although a rough estimate from the map shows that it contains only 2,500 square miles, which means that the density of population is here 2,400 per square mile. The Owari plain has about a million and a half people in its estimated area of 672 square miles, giving a population density of 2,232. The Osaka plain supports two and a half million people within 400 square miles, which shows that on the average there are 6,250 occupants to every square mile. Belgium, the most densely populated country in the world, with its average number of 652 (1910) per square mile, seems meagerly inhabited when compared with these crowded plains. Most of the people are massed in cities even though they are largely engaged in agriculture; for instance, the three main cities of the plain, Kobe, Osaka, and Kyoto, contain over two million people. Osaka alone has nearly a million and a quarter within her less than nine square miles, giving about 142,000 souls per square mile (Census of 1908). It has been recently pointed out that "the city of greatest density of population appears to be Paris, with 88,000 people to the square mile."[1] How little right Paris has to this distinction is brought out by these statistics of Osaka. Even Manhattan Borough, New York City, has only 106,000 (1910) people to the

[1] The Anthropography of Some Great Cities, Prof. Mark Jefferson, Bulletin of the American Geographical Society, p. 540, September, 1909.

square mile. The great volumetric density of population in Osaka is appreciated even more strikingly when it is remembered that houses in Japan are rarely over two stories in height, and usually one, because of less liability to destruction from earthquakes and danger to life during fires. It can be readily appreciated that every room in every house is used to the fullest extent, that sidewalks are almost unknown, that streets are narrow indeed, and open spaces rare, as is shown in Pls. VIIIb and XIIb.

Outside of the cities, the surface of the young coastal plain is densely covered with profitable vegetation, as illustrated in Pls. IIa and b. Here the phrase " intensive cultivation " has an added significance. Not only are the natural fertility of the soil of the plain, and the water that falls on the plain, fully utilized, but the adjoining less productive regions are drawn upon for contributions to increase the vegetable growth there. The slopes of the dissected oldland yield leaves and twigs from shrubs or trees to be made into fertilizers for the plain. The sea supplies freely of its fish and weeds for the same purpose, and the urban areas contribute cooking waste, fuel waste, and human waste. The rain that falls upon the oldland is carefully conserved to augment the productivity of the plain through irrigation. Rice seems to be best adapted to respond to this concentration of incentives to growth; hence the young coastal plain is an almost continuous checker board of rice paddies when the season permits its growth. At other times cold weather crops such as wheat, barley and peanuts are utilizing the land.

*Transportation.*—The ease of transportation in any direction over the young coastal plain is an element quite equal in importance to its high adaptability as an agricultural area. The two together explain the rapid progress in the development of industrial centers and commercial ports. Because of the ease of transportation over the plain the movement of goods and people is greatly stimulated so that it is used much for such a purpose, not only among points on the plain itself, but between the oldland and the sea.

Railroads have been extended more over these plains than over any other equal area in the Empire. Fig 1 shows the contrast between intra- and inter-plain routes. Electric lines are confined even more exclusively to the plains, while roads here form a complete network in contrast to the meager number in the mountainous oldland where they are confined to the larger valleys.

Vehicles drawn by men are the most common on the roads of the plain, as shown in Pl. IXb. This is most economical, not only because of the cheapness of labor but because of the ease with which large loads are wheeled over level surfaces. A man would be required to drive a horse or a bull, so it is wise economy to let the man supply

the necessary muscle while he gives intelligent direction. This is true for both freight and passengers. The usual vehicle is narrow, of less than four feet gauge, to fit the narrow roads, as shown in Pl. VIb, and two wheeled, the more easily to make the right angle turns at the corners of the rice fields. It is no wonder that the modern jinrikisha has flourished on these plains since its invention by an American missionary as a means of carrying those who can afford it, since it so nicely fits the environment.

Nearly all of the rivers crossing the young coastal plain occupy channels within confining banks that have been maintained by the people, the better to utilize the waters for irrigation and to prevent floods in rainy seasons, as illustrated in Pl. IIb. The larger ones, moreover, under this condition of control, better serve the needs of water transportation. On the broader part of the plain bordering the bay head, these river canals connect with an extended system of canals whose construction has been greatly facilitated by the low, level land consisting of unconsolidated materials. Osaka is so thoroughly intersected with canals crossed by numerous bridges that it reminds many travelers of Holland's cities. One of these canals is illustrated in Pl. XIb.

Some of the shorter streams flowing across the narrower young coastal plains have aggraded constantly since the confining banks were first constructed, making it necessary to build them higher and higher, until now the bed of the rivers is well above the level of the plain, as shown in Fig. 3 and Pl. IIb. Thus as the railway line approaches Kobe from Osaka, one has the incongruous experience of passing through three tunnels on the young coastal plain, where three rivers have so aggraded their courses that it was found easier to build the railway under the rivers than over them.

*Influences of Mature Coastal Plain*—*Cultivation.*—This plain suffers in consequence of two heavy disadvantages that are not found in the young coastal plain. One is that it is now so elevated that practically no water from the larger extended consequent streams can be used for purposes of irrigation; the other that, with mature dissection, level surfaces suitable for rice fields that require almost constant flooding during the growing season, do not exist in mature, as in the young coastal plain, except in isolated portions of the upland surface. The latter disadvantage has been overcome by carefully terracing the slopes. Where they are steep, the terrace field is small and the terrace slope long, as is shown in Pl. XIIa. No matter how much human labor is necessary to build paddy fields, the Japanese are under stern obligation to do so, wherever water can be had for irrigation, because of the paucity of level land, and on account of the great amount of food required by a population of such high density.

It rarely happens that water is obtainable for any extent of the upland surface of the mature coastal plain. Dry crops such as wheat and upland rice, and trees are therefore raised here, as in Pls. VIb and VIIIa. Wherever a consequent or insequent stream is available, there a reservoir is constructed and the slope below terraced for rice, as shown in Pl. IIIa. Between the watered portions of the slopes are often delightful tea plantations, orange groves, or mulberry orchards. Some of the fields are located far from the homes of the owners. To obviate the necessity of carrying implements to and from work many have ingeniously dug caves where thick clay layers of the mature coastal plain are exposed in cliffs, to serve as tool houses, as in Pls. VIb and VIIa.

A Japanese merchant of the Owari bay district, whom the writer visited, has an estate in a narrow consequent valley of the mature coastal plain that well shows nice adaptation of land forms to occupation. His village is called Moroyama, "moro" meaning room, and "yama," hill. The site is indeed "a room made by hills." On a narrow strip of the young coastal plain that articulates with the mature coastal plain, he has rice fields, upon which are grown in the colder season, wheat, barley, and beans. On the lower slopes of the mature coastal plain is a mulberry orchard, on the higher slopes a tea plantation, and on a patch of upland surface of the plain, a grove of trees for supplying fuel. At the lowest level, in easy communication with good roads leading to the railroad, he has a saké factory in which he manufactures the rice into the national strong drink, a soy factory where he converts the wheat, barley, and beans into delicious sauce, a building where he breeds silk worms, another in which girls reel the silk, and still another where the tea leaves are fired. Above, on the flank of the mature coastal plain where the view over his estate is pleasing, he has established a little garden aglow with gay flowers where the employees gather twice a day for lunch and tea.

*Temple Sites.*—The mature coastal plain has one conspicuous advantage over its related seaward neighbor, in that it offers excellent vantage ground for extensive views. Some parts of the upland margin of the mature coastal plain are in the attitude of promontories to the young coastal plain, as shown in Fig. 6. They give charming views across the garden-like young coastal plain to the distant bay, as in Pl. IIb. In almost all cases, they seem to be reserved as sites for temples and shrines, and for tea houses, as is illustrated in Pl. XIIb. The Japanese have, as is evident in their art, a keen appreciation for beauty in landscapes. Much of their religion is nature-worship. They have gods and goddesses of ocean, mountains, rivers, trees and the like. It is therefore to be expected that they should have selected these highly aesthetic promontories as altars for paying devotion to their nature gods. They have enhanced the beauty of the surround-

ings of these chosen spots by preserving venerable pines and graceful bamboos, and by planting cherry trees, azaleas, oleanders, and other flowering shrubs. Here the dwellers on the lower plain come in family groups, on inviting days, make their simple prayers to the gods, and sit around on nearby tea platforms, which are so placed as to command vistas that delight the eye. Their holy day is indeed their holiday.

*Transportation.*—The roads on the mature coastal plain are rarely straight or level, as is suggested in Pl. XIIa, in contrast to those on the young coastal plain where they are always so, as in Pls. IIa and IVb. As a result horses rather than men are here used more with wheeled vehicles, since so much propelling power is needed. Men and women,


FIG. 6.—Showing the young coastal plain (A), the mature coastal plain (B), and the gently sloping back of a tilted block of the oldland (C), such as is found in the northeastern part of the Osaka bay district.

however, transport many goods by supporting the load on the head, while bulls are used as pack animals. When the jinrikisha is used here, it requires two or three runners. Native travel is almost entirely on foot.

*Dissected Fans.*—On their outer margin, the fans provoke nearly the same responses as the mature coastal plain because the dissection is about the same. Near the apex, however, erosion has so thoroughly and deeply carved the fans, as is shown in Pl. VIa, in consequence of the greater height, that even the Japanese do not find it profitable to clear the land of its native growth, for other uses, except here and there where some city dweller occupies a remnant of the initial surface of the fan with his summer cottage, as sketched inconspicuously at the right in Fig. 4.

An interesting minor response to environment is found near the apex of many of the fans. At such places the streams usually have falls as is pointed out above, and since waterfalls are considered beautiful and enjoyed by the Japanese, shrines are often located near them.

Fig. 4 shows a typical instance. On several occasions the writer found a rock from the oldland representing the god at these shrines, as if to give travelers from the plains opportunity to put themselves formally under the protection of the new rock god before entering his domain, or if going in the other direction, to give thanks for that protection, while pausing at the fall line.

*Lake Biwa Plain.*—The young Lake Biwa plain is quite as fertile as the young coastal plain, but it is handicapped as to easy communication with the outside world, being separated from coast centers of population by a mountain barrier. Lake Biwa is over 300 feet above sea level. Therefore, the stream that drains the lake into Osaka bay, the Yodogawa, is interrupted by numerous falls which prohibit its use for navigation. The Japanese have removed the transportation handicap in a way that promises well for the future development of the country. They have dug a new outlet for the lake across a narrow portion of the plain at the south, and then carried it through the mountains in three tunnels of 350 feet, one-half mile, and one and three-fifths miles respectively. This is rudely suggested in Fig. 2b. The difficulty of a fall at the south is overcome by means of an incline, one-third of a mile in length, along which canal boats for passengers and freight are carried in wheeled cradles by means of a cable and an electric motor at the foot of the incline. This is run by a part of the lake water piped to it down the incline, after which this same water supplies a navigable canal that leads to a canalized tributary of the Yodogawa. The other part of the lake water is led to above Kyoto where it furnishes power for mills and factories, and is then used for irrigation. Thus cheap but slow transportation connection for the Biwa plain is made with Osaka bay and much other good is done for industries and agriculture at the same time.

*Block Mountains Oldland.*—This is the region of meager and scattered population, where man is limited in his activities to forestry, grazing, quarrying, extensive farming, or intensive cultivation on a few small terraced fields with high retaining walls. Here is the main source of the wood that is used for fuel and building by the dense population of the plains. Stone was rarely used in construction previous to the opening of Japan to the outside world, but under European influences, in cities especially, stone is rapidly taking its part in building stairways, breakwaters, piers, paving streets, facing canals, and even in the construction of buildings. The nearness of granite mountains to the cities in the Osaka bay district has done much to foster the quarrying industry. Most of the products of the oldland that find a market on the plains are transported thence on the heads of men and women. Human labor alone is used in tilling the terrace fields, the horse being dispensed with, the hoe displacing the plow.

Potentially these mountains are the power producers for the indus-

tries of the plains because of the youth of the streams that flow in them, and more specifically because of the falls at their steep bases, as is shown in Pl. X. A number of them determine the position of some of the 383 hydro-electric power plants of the country which develop over two million horse power (1912), but many powerful waterfalls of the old land still remain to be harnessed.

In these oldland mountains, as in nearly all mountain districts, the people, because of their isolation, are backward as compared with those of the plains. This is especially true in Japan, for it was the dweller on the plains who heard the knock of western civilization half a century ago, and answered it with cordial hospitality, while the mountaineer as yet scarcely realizes that the Empire has a door.

General Survey of Remaining Areas.—The remainder of this paper will be occupied with brief descriptions of the more striking features of the eastward extension of the plains and mountains, and their associates, as interpreted in a cursory survey. Place names used are to be found in Fig. 1. They are given with the hope that some of the readers may have opportunity to visit this attractive country and will have the inclination to extend the study here briefly presented.

On the west of the Owari bay district the railway runs along the young coastal plain tangent to the forward spurs of the mature coastal plain, sometimes turning westward into a broad valley floored by the young coastal plain to take in some village or to find a better place for crossing the wide, shallow rivers. Due west of Yokkaichi, a river mouth port of the young coastal plain, one of the spurs of the mature coastal plain attains an altitude of 230 feet. From this point a magnificent view is to be had of the wide young coastal plain, covered with intensively worked plats and dotted with numerous villages, as shown in Pl. IIb.

Toward the head of Owari bay, a Dutch air is given the outer margin of the young coastal plain, at a few places, by dikes that reclaim for farming land, areas that would otherwise be merely salt marshes. Movable dams let the surplus fresh water off at low tide and prevent the ingress of salt water at high tide.

As Okazaki is approached from Nagoya, the surface of the mature coastal plain is so continuous that the railroad rises gradually to it and follows it for long stretches before dipping into shallow valleys of simple consequent rivers.

Between Toyohashi and Hamamatsu is the large " lake " of Totomi. Its floor is an uninitiated portion of the young coastal plain. At its east and west margins the waves are beating at the bases of the slopes of the mature plain. Sand spits are building across the entrance of this lagoon by tying up the outlying islands—fragments of the mature coastal plain—making an excellent roadbed for the railroad. The

entrance is now about a third of a mile wide. It is said that previous to the year 1499 the lagoon had been closed from the sea long enough to make it fresh, but in that year, an earthquake destroyed a portion of the natural barrier. Salt pans are now worked at favored places along the shores.

As the railroad approaches Kakegawa after crossing the Tenryugawa, it gives an excellent view of the land forms under consideration. It first shows the young coastal plain, then the much dissected outer part of the mature coastal plain, and then less and less dissected portions toward the inner margin. Many cuts here give fine views of the characteristic structure of the mature plain. Kakegawa is about ten miles from the sea and separated from it by a huge outlier of the oldland about which there is a high terrace of the mature coastal plain.

On the south of the Oigawa the surface of the plains is covered by an immense lava flow that seems to have had its source up the Oigawa valley.

As the Fujikawa is approached from Shizuoka, there is a stretch of coast from which the mighty attack of the Pacific in the more open bay of Suruga has removed all trace of the plains. Not enough is left to permit the railroad to go between the oldland and the sea. It is forced to tunnel in oldland rock. But directly at the northeast the young coastal plain is just wide enough to take the track; beyond, it is wide enough for a row of houses besides; farther, it takes a row of fields as well; and still farther, it is wide enough for good-sized villages and their agricultural associates. Then the typical forms representing the mature coastal plain appear, here 60 feet above the lower plain. A few miles beyond an exceptional feature is shown in a 10-foot sea-cliff at the outer margin of the young coastal plain.

After crossing the Fujikawa, lava flows and cinder accumulations from Fujiyama dominate all other land forms until Kozu on the Sagami bay is reached. Here the mature coastal plain comes within 100 yards of the shore and the young coastal plain is cliffed 30 feet. As the coast gets more and more exposed at the north, this cliff increases in height. The surface of both plains is here disguised by dunes of volcanic ashes, few of which are used for agricultural purposes. Near Ofuna a heavy lava flow appears on the plains.

In Yokohama the native quarters, the business section, and most of the hotels are on the young coastal plain, while the residential section for the Americans, Europeans, and well-to-do Japanese is on the mature coastal plain, "the Bluff" in the vernacular. Residents of the Bluff have been much hindered in the past because of the difficulty in getting water in times of fire and even for ordinary purposes, because the city's reservoir was on a fragment of the initial surface of the mature coastal plain only slightly higher than the Bluff level. Now a new reservoir is being completed several miles to the west of

the city on the higher parts of the mature coastal plain. The city is bounded on the north by one spur of the mature plain; on the south by another; and a third, between them, intrudes itself quite to the center. From the summit of the forward part of the third spur, the Noge-yama, an excellent view is to be had of the whole city, the harbor, and on clear days, of Fujiyama. It is reached by a flight of a hundred stone steps, as shown in Pl. XIIb, and is crowned, as might be expected from earlier observations on such points, by shrines of both Shinto and Buddhist gods, and by tea houses.

From Yokohama to Tokyo both plains widen gradually. The railway runs tangent to the projecting spurs of the mature coastal plain, and has large station villages at the points of tangency, as is often the case elsewhere. Yokohama has taken vast amounts of sand and clay from the higher plain north of the city for building up the low land along the coast, exposing fine cuts showing structure. In Tokyo the young and mature plains determine the topography. Here the mature plain is thoroughly dissected, forming many more or less isolated hills of varying heights, as well as miniature plateaus. Upon these are located parks, palaces, observatories, and schools, as well as many temples. To reach many of them, it is necessary for the traveller to leave his 'rikisha on the young coastal plain and climb a steep slope. He often has the choice of the men's staircase, which is straight and difficult, or the women's staircase, which is circuitous and more comfortable. The average height of the mature coastal plain is about 75 feet, thus conveniently permitting 100 steps to be made in the staircases, which is one of the magical numbers in Japan. The southern half of the city occupies an area that was naturally the northern part of the Tokyo bay or lagoons. It was reclaimed several hundred years ago by the use of earth taken from the fragments of the nearby mature coastal plain.

Conclusion.—The whole region of Central Japan here considered is eloquent to the geographer of the inconstancy of the position of the boundary between the land and the sea, and of the strong and varied influence of land forms upon an insular people who have been compelled to adapt themselves nicely to their environment under the high pressure of a dense population.

The recent rapid growth of the land, physiographically, in this region may be taken as symbolic of the recent rapid growth of the people, historically, in modern culture. The block mountains may be taken to stand for Japan's high and ancient oriental civilization—conservative and exclusive of modern activities—like the mountain people among them; while the coastal plains, recently uplifted, stand exposed to the pulsating, vitalizing influence of the ocean, anxious to be recognized as the best favored of their kind, even as the people who occupy them.

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# ECONOMIC ASPECTS OF THE GLACIATION OF WISCONSIN *

R. H. WHITBECK

CONTENTS



Introduction.—Investigations, more or less thorough, have been carried on for the purpose of determining whether or not the soil of the glacial drift is superior to the soil of the adjacent area beyond the terminal moraine. Most of the published reports of these investigations state that the glacial drift is more productive than the older soil in the same general region. It is quite commonly believed that the mantle of drift spread over the northern United States, excluding parts of New England, has made better soil than would otherwise have characterized this area. There are areas in the upper Mississippi Valley which were not improved for agricultural purposes by the kind

* This paper is the outgrowth of three closely related pieces of work. Some of the preliminary work was presented in a paper at the Pittsburg meeting of the Association of American Geographers, in December, 1910, and was published in The Bulletin of the Geographical Society of Philadelphia, July, 1911, Volume IX, No. 3. A very considerable amount of additional work was done under the writer's direction by Miss Mildred Aldrich and was presented for a graduation thesis in the University of Wisconsin in June, 1912. Further work was done by the writer, and a summary of the results was presented at the Princeton meeting of the Association, January 1, 1914.

of drift deposited upon them. Such, for example, are the sand barrens in northern Wisconsin and Michigan. So commonly is it stated that glacial soils are of superior quality, and so generally is it assumed that the net effects of glaciation have been economically beneficial to man, that few people seem to have taken the opposite view.

Agricultural reports show, however, that one of the very best farming counties in Wisconsin, Lafayette County, is in the driftless area. The notable excellence of some of the farm lands in other parts of the driftless area seemed to cast doubt upon the general thesis that glacial soils are of better quality than the residual soils of those same regions would have been if no glacier had disturbed them. A member of the field staff of the Wisconsin Geological Survey expressed doubt regarding the general superiority of the glacial soils in the State as compared with the non-glacial. It seemed worth while, then, to take up the problem and to apply as many tests, from as many different angles, as possible.

The investigation was not undertaken for the purpose of proving either the affirmative or the negative of the question, but to establish the facts in the case, whatever they might prove to be. No factor which might affect the results has knowingly been omitted. When, for example, areas were to be compared with respect to value of land or crops, an effort was made to select two areas which have an equally favorable location with respect to large cities, for cities invariably increase the value of farm land and farm products in their neighborhood. Furthermore, the comparisons have been made in a variety of ways and with many areas, in the hope that mere accidents or exceptional conditions may be deprived of any material effect upon results. The inquiry was later broadened so as to include other economic aspects of glaciation besides the agricultural, such, for example, as the effect of lakes and water power.

The State of Wisconsin offers an exceptionally favorable area for this comparative study, for reasons which will appear. The northern half of the State is omitted from consideration because (1) it is geologically unlike the southern half, and (2) it is in a wholly different stage of economic development. Only a minor part of northern Wisconsin is agriculturally improved. But the eastern and western portions of the southern half of the State are underlain by the same kinds of rock, have been settled and cultivated the same length of time and so have had equal opportunity to prove their respective agricultural and other possibilities. It is true that three of the counties in the Driftless Area, owing to valuable deposits of lead (also zinc), were well populated earlier than any of the glaciated counties. Otherwise, the settlement of the driftless area and of the glaciated area went on at much the same rate. The driftless region is crossed by the Missis-

sippi River, a fact of consequence during several decades when that river was an important commercial waterway. On the other hand, the glaciated area has Lake Michigan on its eastern border, a fact of large importance in later years.

General Features of the Driftless Area.—This region includes over 9,000 square miles in the southwestern quarter of the State, overlapping very slightly the adjacent parts of Iowa, Minnesota and Illinois. Time after time in the geologic past, great lobes of the glaciers which pushed into the upper Mississippi Valley have advanced upon this region, sometimes entirely encompassing it, yet never covering it. So far as I know, no other spot in the world has had such an experience. Glacial geologists who have worked in the upper Mississippi Valley and especially in Iowa, believe that they have conclusive evidence of several glacial advances and retreats separated by long interglacial epochs. In each of the advances the ice has closed about the driftless area, sometimes on three sides, sometimes on all sides. This fact becomes still more striking when it is known that the driftless area is not an elevated region. On the contrary, much of it is about the lowest part of the State, including portions of the Wisconsin and Mississippi Valleys that slope and broaden toward the south. The halt of the ice-front in practically every instance occurred on lands of small relief; so the glacial advance was not checked by any barriers in the topography of the driftless area itself.

A discussion of the cause of this peculiar phenomenon is not intended here. It will be found in the 6th Annual Report of the United States Geological Survey.[1] Suffice it to say that the cause, whatever it may have been, persisted for a long time, for it was equally effective in every one of the glacial epochs, which together involved a vast period of time. This cause is believed to be connected with two facts; one, that the driftless area lay approximately between the western margin of the Labrador ice sheet, and the eastern margin of the Keewatin sheet; second, the fact that the highland of northern Wisconsin and Michigan diverted the ice of the Labrador sheet to the right along the Lake Superior depression, and to the left through the Lake Michigan and Green Bay depressions, and that the latter was not able to unite with the ice on the west of the driftless area until it had pushed well to the south, leaving an intervening area unglaciated.

The driftless region of Wisconsin is essentially a lowland gently sloping toward the Mississippi and Wisconsin rivers. The geological formations which underlie it are the same as those which underlie the glaciated portion of southern Wisconsin. There is no reason to suppose that the preglacial topography of one part of southern Wis-

[1] By T. C. Chamberlin and R. D. Salisbury, pp. 205-322; Origin of the Driftless Region, p. 315. Washington, D. C., 1886.

consin was greatly different from that of the other, for that topography was based upon the underlying rock formations which are substantially the same in the drift covered area as in the driftless area. This is especially true of a strip eighty miles broad extending across the southern part of the State. Furthermore, a great number of well records collected by Alden and Thwaites shows that the buried preglacial topography has a relief practically equal to that of the present driftless area.

Now, however, there are marked topographic contrasts. In fairness it must be stated that these contrasts are not such as to impress the ordinary traveler. Furthermore, there are just as striking contrasts between different parts of the driftless region as between the driftless and glaciated areas. In fact, there are greater differences between the sandstone region and the limestone region within the drift-


**FIG. 1.—Cross section through a portion of the Driftless Area (Richland Co.), showing rough topography.**


**FIG. 2.—Cross section through a portion of the Drift Covered Area (Columbia Co.) directly west of the region shown in Fig. 1, and on the same scale.**

less area, than any differences which have resulted solely from glaciation. Rarely is it possible to note just when you pass the border from drift to driftless country. The state geological survey recognizes drift of several different ages, the older underlying the younger, but protruding here and there. The last—or Wisconsin—drift sheet everywhere terminates in a conspicuous belt of hilly moraines from two to twenty miles broad. But in many cases the earlier driftsheets have absolutely no terminal moraine; they simply blend into the driftless region imperceptibly, and even a trained observer frequently cannot tell where the older drift sheet ends.[2] Of course, outwash material often extends considerably beyond the line actually reached by the glacier.

Geologically the surface rocks of Wisconsin may be divided into three groups. Most of the northern half of the State is a region of ancient crystalline rocks. The middle portion is a region of rather soft Cambrian sandstones. This is enclosed on three sides, east, south

[2] Chamberlain and Salisbury, Preliminary Paper on the Driftless Area, 6th Annual Report, U. S. G. S., 1886, pp. 210, 211.

and west, by limestones, under which the sandstone lies. The driftless area is practically all in the sandstone and limestone belts. Probably the limestone originally completely covered the sandstone, as it now covers it on the southern, eastern and western portions of the State. The limestone is resistant. The underlying sandstone is weak.


FIG. 3.—Generalized map showing the three main classes of rock in Wisconsin and the boundary of the Driftless Area. From Bull. XXVI, Wisc. Geol. and Nat. Hist. Surv.

When streams have eroded their valleys through the overlying limestone and are working in the softer sandstone below, a characteristic type of topography is produced. The limestone remains as a capping layer on top of the hills. The underlying sandstone weathers back readily on the valley-sides as far as the capping layers of harder limestone permit. This produces a series of branching valleys separated by mesa-like divides. The drainage of this region is mature and developed with remarkable symmetry. The streams branch and the branches subdivide in dendritic pattern (Figs 6, 7). Many of the hill tops are flat, and the valley sides steep; the streams flow in well-graded channels;

there are no lakes and no waterfalls; swamps are absent, except in certain sections near enough to the glacial border to have their streams clogged by outwash or valley trains.

Further south, while the steep-sided valleys with the mesa-like uplands between are not seen, the drainage pattern is, nevertheless, perfectly dendritic, and orderly topography greets you on every hand.

Topographic Features of the Glaciated Area.—Pass now to the area covered by the latest drift. At once a change occurs. The valleys are filled or half filled with mounds and hills. There is no uniformity in the details of the landscape. The symmetrically branching valleys which characterize the driftless area in the limestone region are nowhere in evidence. Streams wind about in confusion. Headwater divides are difficult to locate. There is no system to the stream courses. A branch stream may flow nearly north to join a trunk stream that flows nearly south. Large areas have no drainage, and swamps and lakes are met with on all sides. The one impressive fact is that everything on the surface is disordered and yet to it all there is a rounded and graceful contour.

The work of the glacier in the non-resistant sandstone was a crushing and leveling process. In the resistant limestone, the glacier rounded off the elevations and eroded some valleys a good deal, tending on the whole to a reduction of the relief and an obliteration of most of the steep slopes.

Differences in Drainage Systems.—The most conspicuous of the contrasts between the two portions of the State is the prevalence of lakes and swamps in the glaciated region and the entire absence of lakes and the rarity of swamps in most of the driftless region. (Figs. 4 and 5.)

A map of the drainage system of the Wisconsin River (Fig. 6) brings out some emphatic contrasts. I know of no other case in which a single river system presents four such distinct types of drainage. The river is about 400 miles long. Its headwaters include such a labyrinth of lakes and lakelets (said to be 1400) that many of them cannot be shown on a map of ordinary size. The northern quarter of the course of the Wisconsin is thus an extreme type of glacially obstructed drainage.

The second quarter of its course is through the older drift. Every lake has disappeared. The swamps are drained. The tributaries divide and subdivide and the tree-like pattern is completely developed.

The third quarter is as youthful as the first, but of a wholly different type. Here the river traverses a wide sandy plain of recent origin. Few tributaries have yet developed.

The last quarter is in the driftless part of the limestone area, and the pattern shows how completely the river and its branches have


FIG. 4.—Driftless Area, Wisc., immediately west of terminal moraine.

penetrated every square mile and established a perfect system of drainage.

The eastern half of the Rock River basin is in the drift and the western half in the driftless area. The map tells its own story (Fig. 7). The well-nigh perfectly graded courses of the main streams in the driftless area are not favorable to the development of water power.

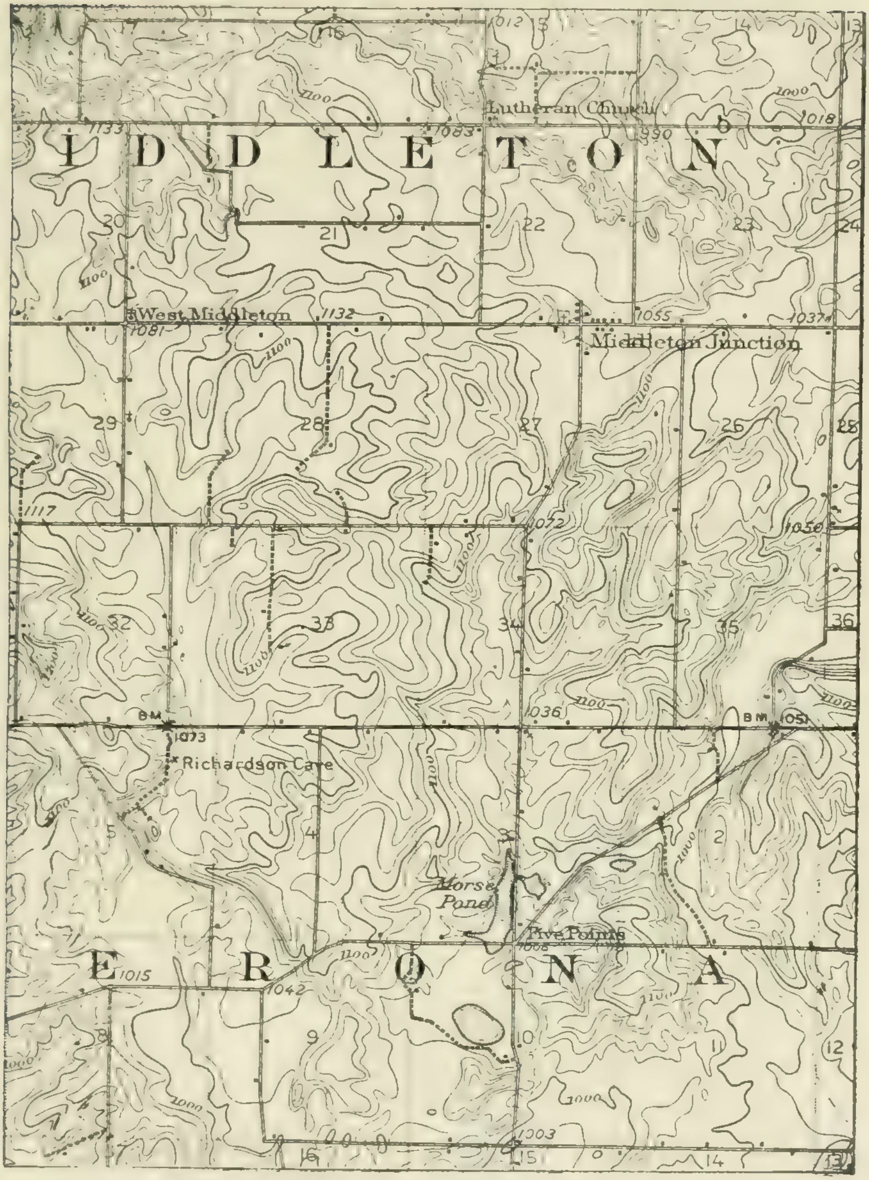



Fig. 5.—Drift Covered Area, immediately east of terminal moraine.

Such development is possible in some localities, but the very fact that eight-tenths of the water power developed in the State is in the glaciated area is significant.

Differences in Soil and Agricultural Conditions.—Turn now to contrasts in soil and agriculture. The best soil of Wisconsin is not always the drift. Some of the richest lands are the residual soils

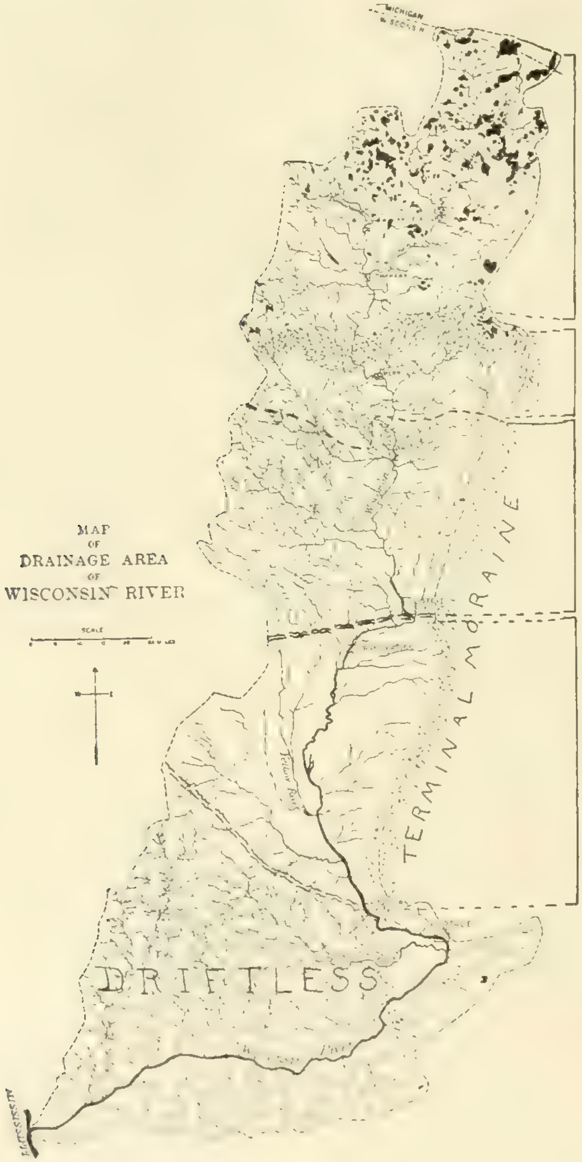



**Fig. 6.—Drainage Area of Wisconsin River.**
**(Modified from cut in Bull. XX, Wisc. Geol. and Nat. Hist. Surv.)**

of the limestone area, over parts of which loess has been distributed. The poorest are in the sandstone area. The older drift is often better soil than the adjacent younger drift. The limestone soils, whether residual or transported, are decidedly superior to the sandstone soils.

In discussing the effects of glaciation upon agriculture, it will not be forgotten that the glaciers brought in enormous quantities of bould-

ers, and introduced hundreds of swamps and lakes at the same time that they were performing the beneficial work of mixing and introducing new soil and smoothing the surface of the land.

PROPORTIONS OF IMPROVED LAND IN THE DRIFTLESS AND GLACIATED AREAS.—According to the United States Census of 1910 the fifteen counties which are wholly or largely in the driftless area consisted of 43.5% improved farm land and 56.5% of unimproved land. The 26 counties (in the southern half of the State) which are wholly

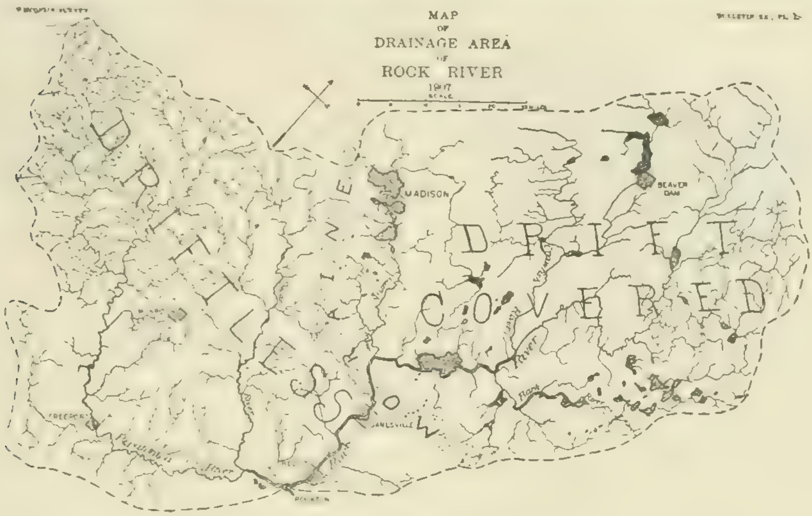


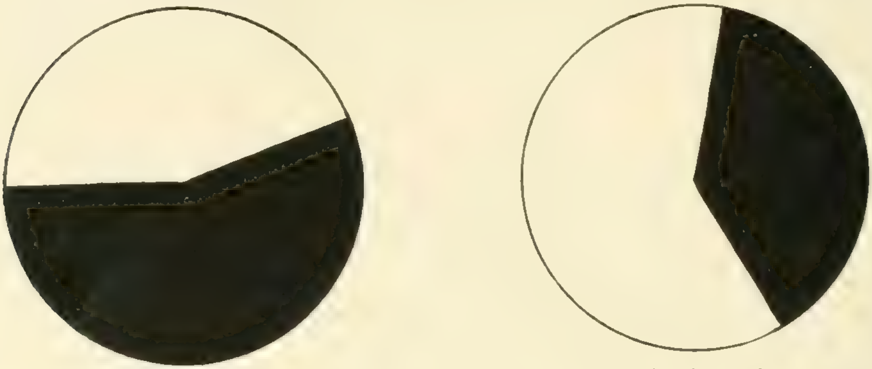

FIG. 7.—Drainage Area of Rock River.

or largely covered with drift, consisted of 61% of improved farm land and 39% of unimproved land, an excess of 17.5% over the driftless area.

The State Census of 1905 shows that in the fifteen driftless counties, the average value of farm lands and farm buildings per county was, in round numbers, $12,000,000, while in the 26 glaciated counties the average value was nearly $18,000,000 per county. On account of the greater number of cities in the glaciated area, and the consequent influence of these in increasing the value of neighboring farm land, the actual bearing of these figures upon the present question is complicated.

For purposes of definite and careful comparison, twelve typical counties were chosen, six in the sandstone belt and six in the limestone. Of all the land in three driftless sandstone counties, 37.2% was improved farm land in 1910, while in three glaciated sandstone counties, 48.2% was improved, an excess of 11% in favor of the glaciated area. In the three glaciated sandstone counties, the value of all crops per square mile was about $400 more (10%), than in the three driftless

sandstone counties. Of all land in three driftless limestone counties, 60.5% was improved in 1910, while in an equal number of glaciated limestone counties the per cent was 70.3, a difference of 10% in favor of the glaciated lands. The difference in productivity is notable, being about $1,400 per square mile—31%—greater on the glaciated limestone soils of these counties than on the driftless soils. In this area



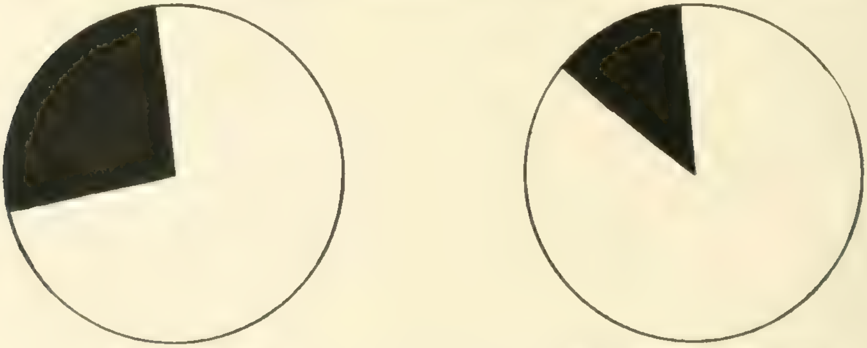
Driftless
White—Improved Land, 43.5%
Black—Unimproved Land, 56.5%

Drift Covered
White—Improved Land, 61%
Black—Unimproved Land, 39%

FIG. 8.—Proportion of unimproved land in 26 counties wholly or largely drift-covered, and in 15 counties wholly or largely driftless.

the limestone lands seem to have benefited more by glaciation than did the sandstone lands.

The question naturally arises, why is there a larger percentage of improved land and higher productivity per square mile in the region



Driftless Area, 26%

Drift Covered Area, 12%

FIG. 9.—Proportion of land in woodland and woodland pastures in Driftless Area and in Glaciated Area.

over which the drift is spread? Two explanations are possible: (1) drift soil may be better than residual, or (2) drift topography may be smoother, permitting the cultivation of more of the land. The high prices of farm land and of farm products make it seem altogether likely

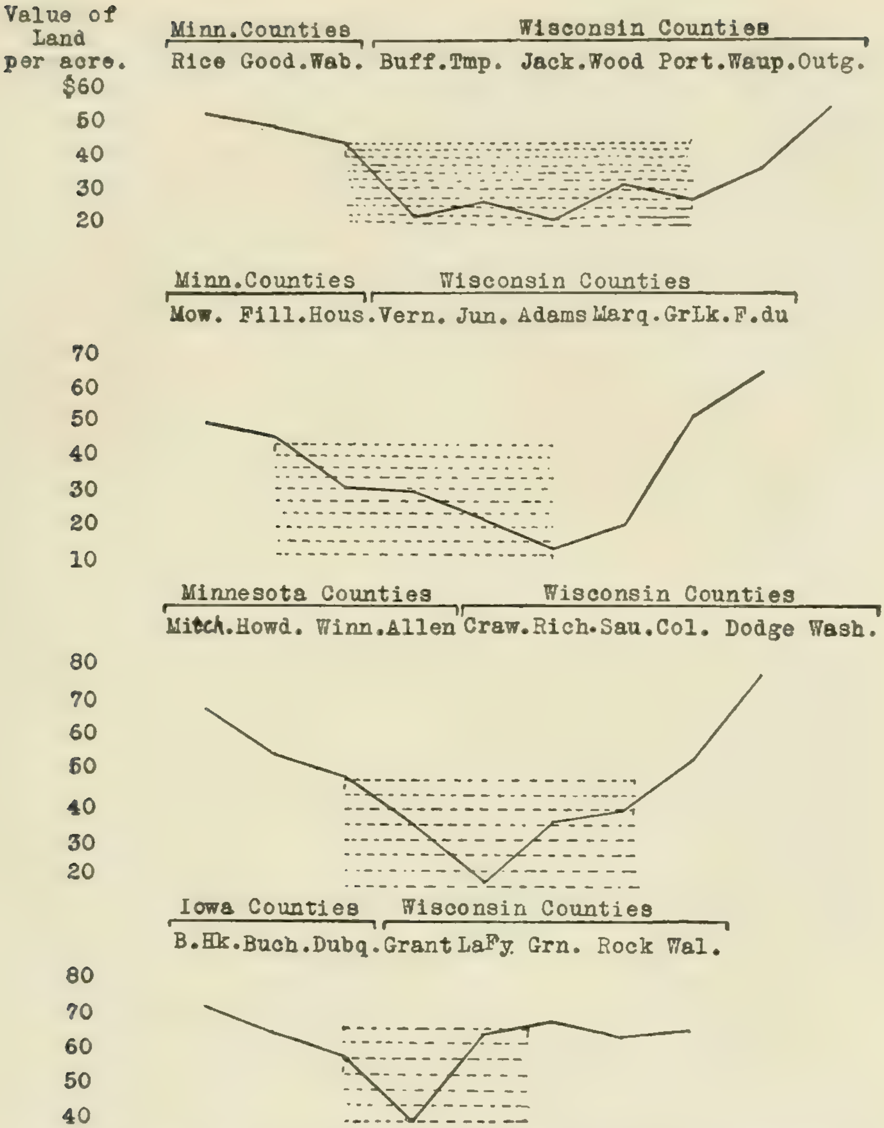



FIG. 10.—Curves showing the average value of farm land and farm buildings per acre in four rows of counties extending from the Glaciated Area on the west across the Driftless Area into the Glaciated Area on the east. Cross lined portions are driftless.

that, in any of the older counties, as much of the farm land will be improved as possible. In southern Wisconsin, about the only land which is left unimproved is swamp land and steep hills. A trip through southern Wisconsin, or an inspection of topographic maps, shows that the swamps are mostly in the drift covered area, but that the topo-

graphy in the driftless area (in the limestone belt) is much rougher. The mantle of drift naturally reduced the relief of the land over which it is spread, and rendered a larger proportion of it fit to cultivate. Computations, based upon U. S. Census figures of 1910, show that while 27% of the driftless area of southern Wisconsin is allowed by its owners to remain in woodland or woodland pasture, only 11% of the drift area is allowed so to remain. Since the woodland and woodland pastures are largely those parts of the farm which are hilly and so are difficult to cultivate or mow, it appears that there is more than twice as much such land in the driftless area of southern Wisconsin as in the glaciated. The driftless area averages over 126,000 acres of woodland per county, while in the drift covered area under consideration, there are only about 50,000 acres of woodland per county. From this it seems that the drift sheet added some 75,000 acres per county to the land that is smooth enough to cultivate or mow. To offset this in part, there are, *on an average,* some 40,000 acres of swamp land per county to be charged against the glacier, leaving a net gain of something like 35,000 acres per county.

Value of Farm Land and Farm Buildings.—The problem was next attacked along the line of the comparative value of farm land including buildings. Four rows of counties, beginning in the glaciated area on the west, crossing the driftless area and ending at Lake Michigan on the east, were selected. Figure 10 shows the counties which are considered. In each county the average value per acre of farm lands, including buildings, was found (U. S. Census of 1910). These values are graphically shown in Fig. 10. It will be noted that the curves all trend downward as they are entering the driftless area from the west, and all except one trend abruptly upward on the east, when they pass out of the driftless area into the drift. Without an exception the counties in which the average value of land is lowest, are in the driftless area. (In fact the average value of the farm lands and buildings in the drift covered counties is about double that in the driftless counties.) The real point here brought out is easily misunderstood. It is entirely possible that there is some land in the driftless area which is equal to the best in the drift, but the *average value per acre of all the land in a given county* is invariably less in the driftless than in the glaciated counties in each row. This may result either from (1) the superiority of the glacial soil or (2) a smoother topography. At this point, no effort is made to determine which is the case. When the figures are placed in columns and the average of each column is found, the results are impressive. [Figures from U. S. Census of 1910.]

AVERAGE VALUE PER ACRE OF ALL FARM LAND IN 39 COUNTIES

| Drift. | Part Drift. | Driftless. |
|---|---|---|
| $45.50 | $42.20 | $24.40 |
| 28.00 | 32.35 | 28.20 |
| 38.50 | 46.70 | 23.10 |
| 55.50* | 51.00* | 32.75 |
| 57.75* | 62.00* | 32.55 |
| 52.20* | 70.75* | 25.70 |
| 45.00 | | 17.25 |
| 52.00* | $305.00 | 38.25 |
| 22.00 | Average, $50.80 per acre. | 21.50 |
| 51.00* | | 39.60 |
| 67.50* | | 40.60 |
| 65.30* | | 41.40 |
| 57.25* | | 68.00* |
| 56.60* | | |
| 80.00* | | $433.30 |
| 62.00* | | Average of 13 counties, $33.30 per acre. |
| 96.00* | | |
| 67.60* | | |
| 70.10* | | |
| 69.40* | | |
| $1,139.20 | | |
| Average of 20 counties, $56.90 per acre. | | |

* Counties with average value of all land above $50.00 an acre.

In the above figures, two Wisconsin counties which contain cities of considerable size, and another county lying near Milwaukee, are omitted from consideration. If these were included, the average value of land in the drift-covered region would be still higher. It will be noted that in fifteen out of the twenty glaciated counties, the average value of all land is above $50.00 an acre, while in only one of the thirteen driftless counties is this true.

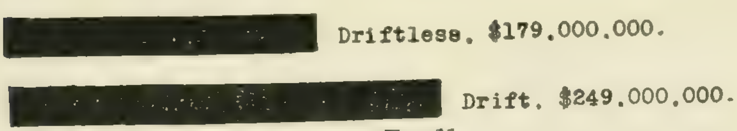



FIG. 11.

No. 1 represents the total value of farm land and farm buildings in fifteen driftless counties in 1910 (U. S. Census).

No. 2 represents the same for fifteen glaciated counties, lying immediately east of the former.

A fact quite unconnected with character of soil accounts for a portion of this difference in the average value of farm land; the Mississippi River flows through the driftless area, and this river and its tributaries have cut the land into a region of steep hills and narrow valleys, a kind of topography unfavorable to agriculture.

In value of farm lands and farm buildings, four *average* counties

in the drift area exceed the four *best* agricultural counties in the driftless area.

COMPARATIVE VALUE OF CROPS.—The next comparison aimed to discover the relative productivity of glacial and non-glacial soils. Comparisons were first made between the glaciated and driftless parts of the four counties which are crossed by the terminal moraine. Two of these, Portage and Sauk counties, are in the sandstone belt; and two others, Dane and Green, are in the limestone belt. The average value of all crops per square mile was (in 1905) $1,968 and $2,690, for the driftless parts of the sandstone and limestone counties respectively. For the glaciated parts of the same counties it was $2,776 and $3,828 respectively for the sandstone and limestone belts. In each case the value of all crops per square mile of territory is over 40% greater in the glaciated parts of the counties than in the driftless parts of the same counties. (Fig. 12.)

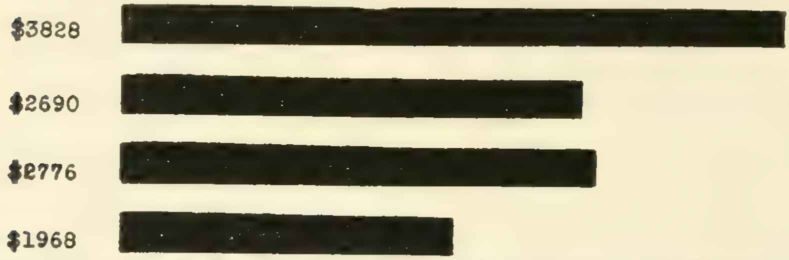



FIG. 12.—Average value of all crops per square mile in the driftless and glaciated halves of four counties crossed by the terminal moraine. Over 40% difference in favor of glaciated lands. Upper two are limestone counties; lower two are sandstone counties.

The next comparison was made by taking two continuous chains of townships, one chain parallel to the terminal moraine and about 6 or 8 miles from it on the driftless side of the moraine, and the other chain on the glaciated side. In the sandstone belt, the average value of the five leading crops per square mile was 11% greater in the glaciated than in the driftless townships, while in the limestone belt it was 36% greater. Comparing all of the driftless townships with all of the glaciated townships, there was an excess of 23% in favor of the drift-covered lands.

Next, twenty townships chosen at random in the driftless area (ten in the sandstone and ten in the limestone) and twenty townships in the glaciated area (ten in the sandstone and ten in the limestone) were taken and the average value of the five leading crops per square mile was computed. This showed a difference of 23% in favor of the drift soils in the sandstone belt, and 38% in the limestone belt. Considering the sandstone and limestone belts together, the difference was about 30% in favor of the drift-covered townships. (Fig. 13.)

The three foregoing comparisons involve nearly 200 different townships in all parts of the area under investigation. So widely different is the basis of selecting the areas for comparison, that it seems certain that mere coincidences play little if any part. In all of the comparisons showing the value of crops per square mile, the results are obtained by dividing the value, in dollars, of the crops produced in a township, by the area of the township, usually 36 square miles. It will be seen that this comparison does not bring out the relative productivity of glacial and driftless soils, acre for acre, but the relative value of crops per township. A township with less productive

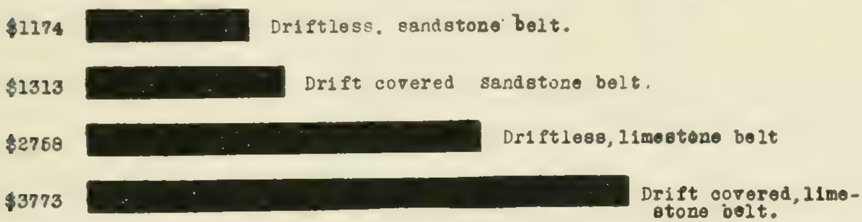



**Fig. 13.—Value of 5 leading crops per square mile of total area of 40 townships—20 driftless and 20 drift-covered—taken at random.**

soil, but having more of its area under cultivation, might show a larger crop value than another township where the cultivated soil was more productive, but which had a smaller acreage under cultivation.

Dairying and Stock Raising.—But may it not be true that the driftless area, being generally more hilly, is more largely given over to dairying and the raising of live stock than is the glaciated area? And as a result may it not be that the deficiency of crops in the driftless area is offset by a higher value of farm animals?

*Dairying.*—Of the leading ten counties in the production of cheese, six—the first, second, fourth, seventh, ninth, and tenth in rank are in the glaciated area. The county ranking third is about half in the driftless and half in the glaciated area. The six and one-half glaciated counties produced in 1910 about 68 million pounds of cheese, or over 10 million pounds each. The three and one-half driftless counties produced 24 million pounds or less than 7 million pounds each.

Of the leading ten butter-producing counties, six—the first, second, third, fourth, fifth, and ninth in rank—are in the drift area and the other four in the driftless. The glaciated counties produced on an average $4^1/_3$ million pounds of butter in 1910, and the four driftless counties produced on an average of $3^1/_2$ million pounds each. Thus, the drift-covered counties on an average led by a margin of over 40% in the amount of cheese produced, and by about 25% in the amount of butter produced.

*Farm Animals.*—The total value of farm animals in five driftless counties, having the largest number of such animals, in 1910 was

slightly over 19 million dollars, and in the leading five glaciated counties it was nearly 22 million dollars, an actual difference of 14% in favor of the glaciated counties. It seems, then, that in the value of crops, of dairy products, and of farm animals, the glaciated area surpasses the driftless to a noteworthy extent.


FIG. 14.—Distribution of cities in Wisconsin. Size of circle is in proportion to size of city.

DISTRIBUTION OF POPULATION AND WEALTH.—In five rural counties of the sandstone belt, the average density of population is twenty-four to the square mile for the driftless area, against thirty-four in the glaciated. In the limestone belt it is thirty-three, and sixty-three respectively. The average density of population in the whole driftless area of Wisconsin was thirty-four to the square mile in 1910, against one hundred and twenty-three in the twenty-seven glaciated counties in the southern half of the State. This is not due to earlier settlement

in the eastern, or glaciated area, for the first rush of people into Wisconsin, as has been pointed out, was into the lead-mining region which happens to be driftless. The fact that the average density of population in the unglaciated part of the State is but little over one-fourth as great as in the other southern and central counties is largely explained by the fact that the development of industrial centers has been much greater in the southeastern quarter of the State than in the southwestern, or driftless, quarter. But why is this? Has it any connection with the glacial episode? Apparently it has, if we may regard Lake Michigan as glacier-born. Lake Michigan determined the location of Chicago and Milwaukee, and either directly or indirectly through the influence of these two cities, has stimulated the growth of the sixty other smaller industrial centers in the eastern and southeastern part of Wisconsin (Fig. 14). In the fifteen driftless counties the average assessed wealth in 1910 was $28,000,000 per county against $66,000,000 in the glaciated counties. While the above is true, it would be unwise to stress this influence of the glaciation of Wisconsin upon the distribution of wealth and population. To a very large degree that influence has been indirect, not direct.

Comparisons of Productivity Per Acre.—We have compared the agricultural wealth and productivity of the glaciated and driftless areas by square-miles, townships, counties and groups of counties, and each comparison places the advantage on the same side—on the side of the drift-covered territory. The question has already been raised whether this shows that the drift actually makes better soil or whether, by smoothing the topography, the drift mantle increases the proportion of land available for agriculture. This can be answered only by comparing the actual *productivity per acre* of the soil in various parts of the drift-covered and driftless country. For this comparison, the three best farming counties of the driftless area and three of the best glaciated counties, all in the limestone belt, were selected.

Average Number Bushels Per Acre in 1909.

| Driftless Counties. | Corn. | Oats. | Barley. | Potatoes. | All Four. |
|---|---|---|---|---|---|
| Richland | 35.4 | 34.6 | 25.7 | 120.0 | 215.7 |
| Grant | 35.6 | 33.2 | 26.5 | 101.0 | 196.3 |
| Lafayette | 36.3 | 35.0 | 25.6 | 105.0 | 201.9 |
| Average | 35.7 | 34.2 | 26.0 | 108.6 | 204.6 |
| Drift Counties. | | | | | |
| Rock | 33.2 | 31.4 | 23.0 | 125.0 | 212.6 |
| Walworth | 44.3 | 36.6 | 30.1 | 87.0 | 198.0 |
| Jefferson | 37.6 | 37.1 | 29.0 | 109.0 | 212.7 |
| Average | 38.3 | 35.0 | 27.3 | 107.0 | 207.8 |

A group of six contiguous counties in the sandstone area shows the following:

| | Average number of bushels per acre | | | |
|---|---|---|---|---|
| Driftless Counties | Corn. | Rye. | Potatoes. | Average. |
| Adams, Juneau, Jackson | 21.0 | 9.6 | 76.0 | 35.5 |
| Drift Counties. | | | | |
| Marquette, Waushara, Waupaca | 25.3 | 11.3 | 107.0 | 47.8 |

From the above tables it appears that in the limestone belt:

1. The yield of corn, oats and barley was a little higher per acre, but only a little higher, in the drift soil than in the driftless.
2. The yield of potatoes was a little higher per acre, but only a little higher, in the driftless soil.
3. When all four crops are considered, the balance is slightly in favor of the drift soil, but only slightly.
4. The largest yield per acre in the case of each crop was on drift soil.

In the sandstone belt, the difference is more pronounced. In each of the three main crops, the average yield per acre is distinctly higher in the drift soil, averaging for the three crops practically $33^1/_3$ per cent.

The foregoing results are in accord with the impression which one gets from traveling through the regions in question, and is in accord with what we might expect from the known facts. The residual limestone soil of Wisconsin, like that of Kentucky or Virginia, is inherently rich and would not be much improved by the addition of the drift. The residual sandstone soil is inherently sterile and would be materially improved by the addition of drift which came from the limestone area on the east, as was true in the case of Wisconsin.

The discrepancy between two sets of results in the case of the limestone belt is significant. It will be recalled that the value of the crops grown *on an average square mile* of the glaciated portion of the limestone belt was from 23 to 40 per cent. greater than that of the crops grown on an average square mile of the driftless limestone belt, while the *average yield per acre* of the land actually in crops was only $1^1/_2$ per cent greater. This seems to prove quite conclusively that glaciation did very materially benefit the limestone belt of the State, *not chiefly by improving the quality of its soil, but by smoothing the surface and thereby increasing the amount of tillable land.* It is also deserving of note that there are few swamps and no lakes in the area whose drainage was not affected by glaciation, but many lakes and swamps were produced in the glaciated area; notwithstanding this, there is a considerably larger proportion of improved farm land in the glaciated area. This seems to indicate that notwith-

standing the swamps and lakes introduced by the glacier, the net result was to increase the proportion of land available for agriculture.

SUMMARY OF FACTS PERTAINING TO AGRICULTURE IN THE GLACIATED AND DRIFTLESS AREAS.—1. Notwithstanding the swamps and lakes in the glaciated area, 61% is improved farm land, against 43.5% in the driftless area, a difference in favor of the glaciated area of 17½%.

2. In the fifteen driftless counties, the average value of farm lands and farm buildings is about $12,000,000 per county, against $18,000,000 in the glaciated area, a difference in favor of the latter of 50%.

3. In three typical unglaciated sandstone counties, the percentage of improved land in 1910 was 37.2, against 48.2 in three typical glaciated sandstone counties, a difference of 11% in favor of the glaciated area.

4. In three typical unglaciated limestone counties, the percentage of improved land in 1910 was 60.5, against 70.3 in the glaciated area, a difference of about 10% in favor of the glaciated counties.

5. In the counties referred to in 3 and 4 above, the glaciated sandstone area produced in 1909, 10% more per square mile, and the glaciated limestone area 31% more than the corresponding unglaciated counties.

6. In the driftless area, there are on an average over 126,000 acres per county of woodland and woodland pasture, against about 50,000 acres per county in the glaciated area. This difference is largely due to the more rugged topography of much of the driftless area.

7. Curves showing value of farm land and farm buildings in four rows of counties, extending east and west across the drift and driftless areas, all bend downward notably in the driftless counties.

8. In the case of four counties which are so crossed by the terminal moraine, that part of their respective areas is glaciated and part driftless, there was in 1905 a difference of 40% in the average value of all crops per square mile, in favor of the glaciated parts of these counties.

9. In the case of two continuous chains of townships on either side of the terminal moraine, there was in 1905 a difference in crop value of 23% in favor of the glaciated townships.

10. In the case of forty townships taken at random, the average crop value per square mile in the twenty glaciated townships exceeded that in the twenty driftless townships by about 30%.

11. Among the counties which lead in number of farm animals, and in the production of butter and cheese, there is a wide margin (from 14% to 40%) in favor of the glaciated counties.

12. In density of rural population and assessed value of property, there is a difference in favor of the glaciated area, which may be

conservatively placed at 50%, but various factors enter into the problem making accurate comparison impossible.

13. When the productivity of glacial and non-glacial soils is compared acre for acre, the difference in the limestone belt is only 1½% in favor of the glacial soil, but in the sandstone belt it is over 30%.

14. The glaciation of Wisconsin enhanced the agricultural output of the glaciated area somewhere between 20% and 40%; in the sandstone belt, mainly by improving the quality of the soil; in the limestone belt, mainly by increasing the amount of land available for agriculture. Upwards of 10,000,000 acres of this glaciated land is in the well-developed part of the State. Assuming the average value of all farm products on this area at $10.00 per acre and assuming the medium figure—30%—as the measure of the enhanced value of the land due to glaciation, then the economic result is $3 per acre or $30,000,000 annually. It seems from the results of the various lines of inquiry recorded in this paper that this sum is not too large.

In drawing the foregoing general conclusions one condition has been assumed as true, which may be called into question. It is assumed that the preglacial topography of eastern Wisconsin was as rough as is the present driftless topography, and that the preglacial sandstone and limestone soils were essentially like these soils now are in the driftless area. So far as the soils are concerned, there is little if any doubt that the assumption is justified. With respect to the preglacial topography, it has already been stated that the well records obtained in the drift-covered area by Alden and Thwaites indicate a preglacial relief approximately as great as the present average relief of the driftless area.

Economic Aspects of Glacial Lakes.—In the northern part of Wisconsin are many hundreds of lakes. In the eastern part of the State, south of the latitude of Green Bay, there are scores of lakes, varying in size from mere ponds to Lake Winnebago, whose area is over 250 square miles. Each lake covers an area of ground which otherwise might be productive farm land. The value of the land thus submerged must be charged against the lakes.

Take, for example, the chain of four lakes near Madison. The area of the largest is 9,700 acres. The average value of land in Dane County, in which these lakes are located, is $73.00 per acre. The approximate value of the land destroyed by the largest lake is $708,000, which must be charged against it. What is there to place in the credit column as an offset?

1. The charm and beauty of lakes make lake shore-lots choice building sites for residences in any city or town so fortunate as to possess a lake front. Lake-shore lots sell for several times as much as ordinary lots. The shore line of Lake Mendota, the largest of the lakes

of Madison, has a length of 22 miles, or 116,160 feet; 15,800 feet of this is in the city of Madison and is valued at considerably above $100 per foot of water front. Beyond the city limits the value of entire farms with a lake shore, as fixed by actual sales, averages $1,200 an acre, or more than 16 times the value of farm land in the county at large. A narrow ring of land around Lake Geneva, Wisconsin, would sell to-day for more than an area of farm land equal to the size of the lake. Around some smaller lakes like Oconomowoc, the ring of lake shore land is worth many times as much as an area of farm land equal to that submerged by the lake. The value of fish and ice annually taken from such lakes reaches many thousands of dollars; and in frequent cases, the value of a city's water supply must be added.

Lakes equalize the flow of streams and thus act to the benefit of down-stream water power, as in the conspicuous case of Lake Winnebago in the Fox River. The maximum flow of the lower Fox in second feet in 1903 was about eight times the minimum, while in the case of the Black River, for example, it was twenty-two times. Along the lower Fox, upwards of 32,000 horsepower is developed, more than on any other river in the State. This valley forms one of the leading paper-making districts of the United States, a fact due largely to the waterpower. The larger lakes, especially Michigan and Superior, modify climate and favor the growing of fruits, and fruit lands are more valuable than ordinary farm lands. The two most successful fruit-producing areas of Wisconsin are Door peninsula, extending into Lake Michigan, and Bayfield peninsula, extending into Lake Superior. Cherry orchards in Door County produce as high as $700 worth of fruit per acre. When all of the credit items are put together it seems that they must exceed the debit item—the loss of the submerged land. Of course the aesthetic value and pleasure-yielding value of the lakes can not be measured in dollars. I think it is safe to say that the people of Wisconsin regard their lakes as an asset, not as a liability.

Water Power.—In 1912 the developed waterpower of Wisconsin was placed at approximately 180,000 horsepower. Nearly all of this was in the glaciated area of the State and, for the most part, owed its existence to rapids and falls of glacial origin. In the southeastern quarter of the State, the drift has so clogged the streams that water power sites are very rare. In the northern half of the State, where greater elevation gives the rivers a higher gradient, waterpower sites are numerous and investigations by the engineers of the State Geological Survey place the available waterpower at a million horsepower. It is computed that the annual saving represented by waterpower over steam power in Wisconsin is about $20.00 per horse-

power. On the basis of 180,000 horsepower now developed in the State, the annual saving would amount to $3,600,000, but it is impossible to state how much of the waterpower already developed or to be developed in the State is actually attributable to glaciation. Relatively little power is developed in the driftless area, and relatively little can be profitably developed; the streams have so perfectly graded their courses that a low, fairly uniform gradient is established, and this is unfavorable to the utilization of waterpower. On the other hand, it happens that the glaciers over-rode that part of the State which might be expected to have afforded most waterpower sites, even without glaciation, namely the northern part.

A basis of comparison is afforded, however, by the Black River and the upper Wisconsin, both flowing in the same kind of rock, flowing in parallel courses and emptying into the same river, the Mississippi. The Black flows 77 miles in the pre-Cambrian area; its watershed is wholly outside the region reached by the Wisconsin ice sheet. The drainage basin has reached a stage of some maturity for lakes are wholly wanting. In the seventy-seven miles, its average fall per mile of 5.8 feet is nearly twice the *average* of the upper Wisconsin (3.1 feet), yet so well is its channel graded that there is but one place where the fall averages as high as nineteen feet per mile. Contrast with this the upper Wisconsin, whose average fall per mile is less than that of the Black but whose course has been more interfered with by glacial deposits. In sixty-six miles there are three places where the fall reaches 40, 47, and 55.6 feet per mile, respectively. It is evident that a river of the latter type, having much of its fall concentrated at a few points is superior for waterpower purposes to a river with even a higher *average* gradient, but having its fall more uniformly distributed throughout its course.

Manifestly, anything like an accurate estimate of the economic value of glacier-born waterpower in Wisconsin is out of the question. But, assuming that three-fourths of the power already developed is due to the rejuvenation of streams by glaciation, the amount will be 135,000 horsepower. The State Geological Survey's engineers place the annual saving at $20.00 per horsepower, making a total annual saving of $2,700,000. The actual value to the State does not end with the saving effected, for some important industries—particularly the making of paper and pulp—would not have been located in the State but for the available waterpower. The product of this single industry amounts to thirty million dollars a year. There is no desire to make inflated claims regarding the importance of this item to the State. The value of glacier-born waterpower, however, is real and it is considerable, certainly measured by several millions of dollars annually.

CONCLUSION.—In making the studies reported in this paper, the writer had no preconceived notions which he wished to prove. If, after making the thoroughgoing comparisons which were made, the results had indicated that the glaciation of Wisconsin had proved to be an injury to the State, they would have been recorded just as willingly as they have been with the present outcome. Effort has been made to get at facts, nothing else. It turns out that the findings are in accord with those reported from similar investigations in some other States, although I am not acquainted with any published reports of inquiries which have attacked the problem from so many different angles as has this one.

If the actual agricultural conditions in the driftless and glaciated areas were not markedly different and were not markedly better in the glaciated area, then it is not conceivable that in every one of the numerous comparisons made, the balance should always be found on one side. In such a series of comparisons, there is only one way in which the glaciated area can always appear to be agriculturally superior, and that is by actually being superior. No such unbroken series of findings, always indicating the same thing, is conceivable, except on the assumption that the facts and the findings are in substantial agreement.

It may be held that this investigation does not prove that the eastern part of southern Wisconsin has been greatly improved for agricultural purposes by glaciation, since we have no means of accurately knowing what the preglacial conditions in *that part of the State* were. But the investigation does prove that the glaciated part of southern Wisconsin is *now* agriculturally superior to the driftless part, and this carries with it a strong presumption that glaciation is the main cause of the superiority. The following facts appear to be established:

1. That the sandstone soils were improved in productivity by the admixture of drift which they received.

2. That the limestone belt was materially benefited by glaciation, more, however, through the smoothing of the topography than through actual improvement of the soil.

3. That, notwithstanding the swamps introduced, a considerably larger proportion of the glaciated than of the driftless area is suited to the production of crops.

4. That even dairying and stock raising are more extensively, not less extensively, practiced in the glaciated area than in the driftless.

5. That the superiority of the glaciated area is substantiated by the fact that the value of farm land is materially higher both east and west of the driftless area than in it.

If it is true that in preglacial time the eastern part of southern Wisconsin was essentially like the western part, as its underlying

rocks suggest, then it follows that glaciation has benefited the agricultural interests of that part of the State to the extent of something like $30,000,000 annually, though this is only an estimate based upon the average showing made by a variety of comparisons; $30,000,000 capitalized at 5% amounts to $600,000,000.

There seems to be satisfactory evidence that the lakes and water-power of glacial origin are a net economic gain of at least a few millions, and perhaps many millions, of dollars annually, and this does not include the economic benefits to the State arising from the presence on its borders of Lake Superior and Lake Michigan, benefits of first magnitude but manifestly difficult to evaluate.

## Condensed Summary of Comparisons Between Glaciated and Driftless Portions of Wisconsin

*Comparison of Per cent of Improved Lands.*—Twelve typical counties, 6 sandstone and 6 limestone, excess in favor of drift, 10½%.

*Comparison of Crop Values per Square Mile of Total Area.*—Excess in favor of drift, in sandstone belt, 10%; in limestone belt, 31%.

*Comparison in Per cent of Uncleared Land* (southern half of State.)—In driftless area, 27%; in drift area, 11%.

*Comparison of Crop Values per Square Mile in Four Counties Crossed by the Terminal Moraine.*—Sandstone, average value all crops per square mile, drift, $2,776; driftless,, $1,968. Limestone, average value all crops per square mile, drift, $3,828; driftless, $2,690. Excess in favor of drift of 40%.

*Comparison of Crop Values in Two Chains of Townships*, one on each side of the terminal moraine.—Excess in favor of drift, in sandstone belt, 11%; in limestone belt, 36%.

*Comparison of Crop Values per Square Mile in Forty Townships Chosen at Random.*—Excess in favor of drift, in sandstone belt, 23%; in limestone belt, 38%.

The foregoing crop-value comparisons involve 200 townships scattered through 40 counties.

*Comparisons in Dairying and Stock Raising.*—Of the leading ten counties in the production of cheese, Nos. 1, 2, 4, 7, 9, 10 in rank are drift-covered; Nos. 5, 6, 8 are driftless; No. 3 is half drift-covered.

Average production of cheese per county, drift, 10,000,000 lbs.; driftless, 7,000,000 lbs.

Of the leading ten counties in the production of butter, Nos. 1, 2, 3, 4, 5, 9 in rank are drift-covered; Nos. 6, 7, 8, 10 are driftless.

Average production of butter per county, drift, $4^1/_8$ million lbs.; driftless, $3^1/_2$ million lbs.

Excess in favor of drift, cheese, 40%; butter, 25%.

In the number of all farm animals, excess in favor of drift counties, **14%**.

*Productivity of the Soil.*—Average of four principal crops, corn, oats, barley, potatoes:

| | Bushels Per Acre. *Sandstone.* | *Limestone.* |
|---|---|---|
| Drift | 47.8 bu. | 52.0 bu. |
| Driftless | 35.5 bu. | 51.1 bu. |
| Excess | 12.3 bu.=33% | .9 bu.=2—% |

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# THE FINAL REPORT OF THE NATIONAL WATERWAYS COMMISSION*

ROBERT M. BROWN

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Character of the Report.—The final report of the National Waterways Commission is one of the most important documents on our waterways that has been issued. There is no doubt that the solution of our transportation problems, in so far at least as the water courses are concerned, has been delayed by stubbornness on the part of individuals and associations in making their special hobbies the pivotal matter of the situation. To some degree the question has become a controversy and this has assumed too much the aspect of a political campaign with vociferations, platforms and slogans. Such a state of affairs is deplorable because the very complexity of the task of inland waterways ought to summon the leaders in this field of endeavor to a broad policy of consideration for every project that has a degree of plausibility. There will be differences of opinions and inevitably widely different remedies will be offered, but these differences are not going to be settled by forensic display. So it is refreshing to read a report where due weight is given to every intelligent opinion and where the discussion is apparently without bias. The two main issues which have distressed waterway conventions are the desired depth of water to be attained in the Mississippi River, the main artery of the

* The Final Report of the National Waterways Commission. Senate Document No. 469, 62d Congress, 2d Session. Final Report of 62 pages. 9 appendices, with a total of 579 pages.

Government Printing Office, Washington, 1912.

The National Waterways Commission was created by Act of Congress of March 3, 1909. The Commission consisted of twelve members of the Senate and House of Representatives with Theodore H. Burton as Chairman. The duty imposed upon the Commission by the Act was to investigate questions relating to water transportation and the improvement of waterways. The preliminary report was submitted to Congress in January, 1910, and the final report in March, 1912.

central portion of the country, and the practicability of reservoirs in preventing floods and in maintaining a low-water navigable channel.

Desired Depth of Water.—In the first of these, the fourteen-foot and the Lakes-to-the-Gulf advocates have been opposed to the nine-foot waterway plan of the Mississippi River Commission. The final report of the National Waterways Commission does not admit the question as one of vital importance, and the only discussion of depth is found in the Preliminary Report of this same Commission, printed as Appendix I of the Final Report, in which two points are presented: first, canals for deep draft vessels are profitable only when these canals connect navigable waters located near each other as the Welland Canal; or when a comparatively short canal will save a great sailing distance as the Panama Canal, or when a large city is situated within easy distance of the coast as in the case of Manchester, England: and, second, the weight of evidence favors, in general, open river navigation to a lock and dam or canalized navigation on the ground of economy. At the same time, it is recognized that if a growth of traffic should eventually be realized, thorough regularization or canalization may be a just demand.

The Reservoir System.—The second point of controversy centers about the reservoir system of flood prevention and low water control. The Report considers this method of stream regulation at some length. The point is clearly made that a reservoir system built primarily for flood prevention will not be practicable as a means of aiding navigation or power development. If it is desired to use the reservoirs for all three functions, it will be necessary to have the reservoir large enough to impound the requisite sum volume of water demanded by each project if acting separately. There is cited the case of the proposed reservoir on the Genesee River. This contract provides for a dam 152 feet high and the volume of water is figured sufficient for all purposes in the scheme of the promoters. The first 32 feet of water are to be held for infrequent use, the next 45 feet of water are intended to raise the water stage during the low water season, the next 55 feet are for power development and of the remaining 20 feet, 15 are planned to lower the flood level and 5 are held in reserve for extreme floods. At the end of the flood season, this top water will be drained off to the level of the water for power development, 132 feet. Such a policy if applied to the Mississippi would probably mean a cost too great in comparison to the protection it would insure. It is a reasonable position to take that the reservoirs on the Ohio River which are proposed for the improvement of navigation cannot be of service, except incidentally, for flood protection and power development, and the theory so persistently advanced that the reservoir system which will give adequate security from overflow of levees will pay their way through the

sale of power cannot longer be reasonably entertained. The conclusions of the Commission on this point are stated carefully, although they leave the question still unsettled. This is a wise policy as much of the answer must be based on experimentation, and this state and municipal governments are beginning to undertake. They do not unreservedly recommend reservoirs, but they do look in the direction of this method of control in the proper time. Their creed is somewhat as follows:

1. The necessity of controlling floods increases with the development of the country. This is not new nor profound, but it is a basal fact in the reservoir scheme because the interest of the cost of the plant must be met by the profits of the protected areas.
2. The using of storage reservoirs becomes more practicable where the value liable to damage is great. This is a paraphrase of the first. The Commission adds that this condition has been attained on some streams.
3. This conclusion states that the Commission does not know on what streams the construction of reservoirs would result in benefits commensurate with the cost.
4. The Federal Government has no constitutional authority to engage in works intended primarily for flood prevention or power development. In this statement there seems to be implied that reservoirs can be built to aid navigation only. Thus in the case of the Genesee River dam of 152 feet, under the charge of the water supply Commission of New York State, the 55 feet for power development would have to be eliminated if it was a Federal contract reducing the height to 97 feet and possibly the 20 foot for flood catchment which would make a still further reduction to 77 feet, or about one-half the proposed height.

Two more conclusions which point out the lines of future investigation are listed. It will be seen that while the Commission appear to be perfectly satisfied concerning the practicability of reservoirs in stream regulation, they hesitate to say that the time is ripe for the building of them on any particular stream. Yet notwithstanding the uncertainty of mind which is stamped on the formal conclusions of the Commission, the entire discussion of the reservoir system is valuable and a contribution.

Influence of Forestation upon Navigation and Floods.—Another subject covered in this Report is the influence of forestation upon navigation and flood prevention, concerning which there are many conflicting opinions in print. In this as in the other lines, the Commission have given an impartial review of the discussion and have reached certain conclusions which, as one might expect, are much more moderate

than the views of the leaders of the controversy over forest influences. No universal law of influence of forests upon precipitation, run-off and erosion is found. The variations of rainfall, slope and porosity of the soil are such that on one stream the effects of forests may be beneficial to stream flow and mitigate floods, while on another the opposite results may be experienced. Moreover, the Commission is convinced that in no case can forests be relied upon to prevent floods or low water conditions, nor will they take the place of storage reservoirs in securing a uniform stream flow. The main benefit of the forest cover lies in the prevention of erosion; and, inasmuch as this conclusion has been reached, there seems to be no reason why forests at headwaters of streams should not be removed if the land is desirable for agriculture providing a proper vegetation cover is given the land or some suitable manipulation of land slopes is undertaken in order to prevent erosion.

THE RAILWAY CONTROL.—The depth of the Mississippi waterway and the reservoir system of control are subjects which have stirred deeply the believers in inland water routes; the effects of deforestation on stream flow is a question that has been discussed, somewhat bitterly I fear, as a concomitant but not as a main issue, but the lack of co-operation between the railways and the waterways is after all the sore spot in our waterway troubles. In two directions, the railroads have blocked the increased use of waterways; first, by the control of water terminals, and, second, by their refusal to co-operate by prorating or otherwise in water shipments. The Commission believes that the proper solution of the terminal question is most vital to the future of water transportation. The railroads own or control a large proportion of the water fronts which are held in a manner adverse to water traffic either by demands for unreasonable terminal charges or by preventing the development of water frontage. For the solution of the problem, the Commission proposes that the state or municipal officials condemn such property for public use. The co-operation of railway and waterway is a more difficult task because there are so many ways open by which, within the letter of the law, a railway company may stifle the intent of the law. There is nothing ethically wrong in lowering rates in competition providing these rates are neither discriminating nor temporary. The shipper or the buyer is interested in waterways only as they reduce the marketable cost of his wares, and consequently he enjoys competition rather than harmony. The tendency of large railroads to combine and the control of railways over waterways are, to be sure, a move towards harmony and co-operation but the elimination of competition establishes a monopoly in a branch of the public service which renders them a subject of control by the Federal Government. The Commission recommends that waterways be under the control of the Interstate

Commerce Commission and be made common carriers—a move which would allow the Commission to establish a connection between rail and water lines by requiring joint rates.

New Canals Proposed.—In addition to the subjects discussed in this review, the United States National Waterways Commission advises the construction of the proposed canal between Lake Erie and the Ohio River near Pittsburgh, and pronounces entirely feasible both the Lake Erie-Lake Michigan artificial waterway and the Anacostia-Chesapeake canal.

The larger discussions of a number of the topics by experts are collected as appendices. Here may be found valuable papers on storage reservoirs by Leighton, Follansbee and Bixby, on forest influences with an extensive bibliography by Zon, on legal aspects by Mooney and on a comparison of American and European waterways by Merchant. Altogether the volume of 580 pages contains a vast fund of information and the pages devoted to the Final Report proper offer a safe and valuable basis on which to found any study of the waterway problem.

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# MEMOIR OF RALPH STOCKMAN TARR

ALBERT PERRY BRIGHAM

Ralph Stockman Tarr was born January 15, 1864, in Gloucester, Massachusetts. He died, after a brief illness, at his home in Ithaca, March 21, 1912, being a little more than forty-eight years of age. In Gloucester his boyhood and youth were passed. What the influence of early environment must have contributed to the main currents of his life was told by one of his fellow teachers, at the funeral service in Sage Chapel, on the campus where he had wrought for twenty years. "For a student of geography few places could have given better preparation than the busy Gloucester of his youth. It was not yet the day of the steam trawler, creeping sullenly in to swell the profits of a trust; instead, fleets of deep-laden bankers, the nested dories shining from their decks, crowded on all sail in the homeward race. High sparred barques discharged salt from Portugal, and handy schooners sailed out past Norman's Woe with cod for Barbadoes and Funchal. The mystery of earth's space, the romance of far flung trade, brooded over the little port."

After he had passed away there was found a writing, not before known to exist. It was written in a small black-bound note book of the United States Geological Survey, in a clear but swift-running hand. It was a short sketch of his early life, made apparently at a single sitting, on the Nugsuak Peninsula, Greenland, September 6, 1906. In this short but absorbing story of experience, he tells the ventures and struggles through which he passed from 1881, a youth of seventeen, until he was far into the midstream of his career, fifteen years later. To follow the lines of this self-revelation, made without reserve but with absolute simplicity, has been to the writer of this memorial, a sacred privilege.

On graduation from the high school in 1881, Tarr's interest in science led him to enter the summer school of the Peabody Academy at Salem. He was unable to continue there, but a talk with one of his teachers planted the impulse to go to college. He determined upon the Lawrence Scientific School and entered at Cambridge in the autumn. He made daily trips over the thirty miles between Gloucester and Cambridge, rising at 5:30 for the 6:15 train, reaching home at eight o'clock in the evening, whose later hours were filled with study. It is no wonder that by June, as he says, he was tired out and somewhat discouraged.

In the summer came an opportunity to assist Professor Alpheus Hyatt in dredging and to study invertebrates in his private laboratory. The following autumn he spent a short time at Wood's Holl, dredging with Professor Baird and then went to the Smithsonian Institution in Washington, where he was given work through the winter and spring. In the summer of 1883 he was at Wood's Holl again, dredging, and beginning to write articles for the *New York Sun, Nature,* and other papers, on deep sea life. This new work offered a further means of self-support and gave him a training in expression which was to be used throughout his life. *Science, Forest and Stream,* the *Presbyterian Observer,* the *Congregationalist, Boston Transcript, Leslie's Monthly* and many other papers received his contributions during this period. His first original paper, on the crawfish, appeared at this time in *Nature.*

At the end of the year he resigned his place at the Smithsonian and returned to Gloucester. In Washington he had found friendships in cultivated homes, which helped to carry him through the years of change and youthful struggle while he was finding himself and driving on, without seeing his way, toward his life work. In the summer of 1884 he made a trip up the Saguenay and into the woods. This was an early expression of his great love for travel and for widening his field of observation. In the fall of 1884 he went back to college, this time living at Cambridge. New opportunity to earn his way and a great impulse in a new realm of study thus came with the acquaintance of Professor Shaler.

Interrupting college with a long and disappointing experience on a western ranch, he returned to Shaler and geology in 1887. His western sojourn had increased his interest in the science and his counsellor and friend helped him to realize a purpose, which, after many vicissitudes, was now shaping itself to grim determination. He now accomplished much work on the geology of Cape Ann, a problem which he says was much too big for his experience. It may in truth be said, however, that the report on that region published in the Ninth Annual Report of the United States Geological Survey is substantially Tarr's work.

The next year he was one of a group of geological students, numbering Whittle, Woodworth, Penrose, Cobb, Ladd, Foerste, Dodge, Collie, and others, an association marked by true fellowship and progress in science. He followed with summer work under Shaler and developed his interest in physical geography and glacial geology. In the fall of 1888 college work was again interrupted by an appointment to the Arid Land Survey. He went to New Mexico, learned stream gauging and the use of meteorological instruments and was promoted from the position of "skilled laborer" to that of hydro-

grapher. Service in Montana followed, and later he spent a large part of 1890 as a member of the Geological Survey of Texas.

Returning to Cambridge he became an assistant to Shaler, continuing his studies under Professors Shaler, Davis and Wolff and receiving his college degree in 1891. He was appointed to the professorship of geology in the University of South Dakota, but having a position already under Wolff in the Archaean Division of the national survey, he declined the call to the west. In the spring of 1892 he was married to Miss Kate Story of Gloucester, and received a temporary appointment at Cornell. There is ample reason to believe that Professor Dana desired Tarr to succeed him in the Yale chair, but he was not successful in bringing about this end. In 1894 Tarr was appointed to the Cornell chair for three years. In 1895 he published his Elementary Physical Geography and accomplished his work in the Chautauqua grape belt. In 1896, worn with many tasks, he spent a short period of rest in the Bermudas, and returned to organize the Cornell expedition to Greenland. This was successfully carried out and added to his experience and productive observation.

Thence to the end, his life was closely linked to Cornell University. His labors as teacher, author, investigator and traveler follow one another with bewildering rapidity. Not best in the way of chronology, can these activities be set forth. The order of events does not count much in a great life, for such a life expresses character and truth, realities far beyond the hampering bounds of time.

Professor Tarr never lost sight of his opportunities as an investigator. He had a restless passion for new truth, which ran side by side with his desire to acquire and interpret the old. In his search he showed contempt for weariness, devoted himself to rapid and almost ceaseless work and took little account of personal danger.

He at once made himself at home in the region about Ithaca. The field was rich in physiographic and glacial problems, and he took up the origin of the Finger Lake basins, the history of the drainage, the evidences of the glacial Finger Lakes, the distribution of the local terminal moraines, and the characteristics of the post-glacial gorges. In more recent years he executed a detailed survey of the Ithaca and seven neighboring quadrangles, and his results appear in the Watkins Glen-Catatonk folio of the United States Geological Survey. This is one of the very few regions in New York whose glacial phenomena have received full areal study and mapping.

Professor Tarr became interested in Alaskan work and spent there the summers of 1905 and 1906 under the National Survey. In 1909 and 1911 he conducted parties in Alaska under the auspices of the National Geographic Society. In 1909 he published, as Professional Paper 64, the Physiography and Glacial Geology of the Yakutat

Bay Region, Alaska. With Martin as co-author he published "Earthquakes at Yakutat Bay, Alaska, in September, 1899." This appeared as Professional Paper 69 of the Survey. The National Geographic Society now has in course of publication a volume on Alaskan Glacier Studies, which deals with the research work in 1909 and 1911 and also embodies the work of Martin in 1910. He also left the nearly completed manuscript of a College Physiography, a production of his maturity, which is now being edited and prepared for publication. Members of the Association recall the vigor, the comprehensive interpretation and the compelling interest of his paper on "Glaciers and Glaciation in Alaska," which he offered as his presidential address at the Washington meeting.

The Greenland work was the basis of several papers, and the years 1901, 1902, 1909 and 1910 were marked by long sojourns in Europe, with many field trips and much active study. During his last year abroad he gratified his love of work in the far north by going to Spitzbergen with members of the Geological Congress. He visited Panama in 1907. Not long before the time of his death he was making plans for a summer in Newfoundland, where he had long desired to study the features of glaciation.

He was positive in opinion but considerate of the views of others. His paper on the theory of the peneplain showed these qualities. Professor Davis in his rejoinder, while controverting Tarr's opinions, recognized the paper as an example of fair and temperate discussion. As time went on he developed a larger and riper interest in human geography, as is shown by many of his papers, especially by some which were offered for the programs of this Association.

His life shows what a great teacher does as a fountain of instruction, inspiration, co-operation and friendship. He loved to acknowledge his debt to Shaler and he exhibited in his own teaching many of the traits of his early master in the earth sciences. He had broad interest in man and nature and he brought the youth and nature together, confident of the result, heeding little the nice precisions of any particular method of approaching a problem. He was able to see beyond the young investigator's crudities and errors, to preserve the young man's respect for his intellectual self and allow him to evolve his own ways of working without hindrance.

A multitude felt his influence at Cornell University. There are to-day many teachers of Geology and Geography whose scientific father he was, and I have never seen one who did not pay credit to the vitality of his teaching and the purity and nobility of his manhood.* There was an atmosphere of geographic interest in which his

* Among Tarr's former students may be named the following: J. A. Bonsteel, U. S. Bureau of Soils; B. S. Butler, U. S. Geological Survey; S. P. Carll, economic

students lived and worked. They found it in him, in his laboratories, in the field and within the ever open doors of a lovely and hospitable home. The thorns that beset his early paths made him sympathize with the hardships and baffled progress of others.

Among his students were many teachers who came to the University for the summer courses. Several years of association with him in this work first brought the writer of this sketch into an appreciation of his sympathetic power as a teacher.

He took much interest in gathering and acquiring the materials of instruction. He fitted others to do the details of this work, and was always surrounded by a group of efficient student assistants. He never allowed himself to be submerged by the numberless material arrangements which tempt and engross some teachers of science. He recognized more than most teachers the necessity of field work, and both his summer courses and the regular courses were securely buttressed by this kind of study.

Professor Tarr produced in rapid succession a series of most important and successful text books. His first ventures were in the field of economic and of high school geology. Next came the first of his physical geographies, which was a major contribution to the pedagogy of geography, and which, in the field of high school work, was the pioneer in making the new geography available. The book had an awakening freshness of treatment and wrought large results in its field. It was followed by later texts on the same subject, and by the writing, in coöperation with Professor McMurry, of one of the leading series of elementary geographies in America. He was fertile in devising helps to accompany his various texts, and there was cut off by his death an attempt at the problems of experimental geography, which promised good not only to teachers but to the growth of the science itself.

A series of articles on the geography of New York state was published in the Bulletin of the American Geographical Society and later embodied in a volume. His pen was fertile in articles for geographical journals, and of the one already mentioned as well as of the Journal of Geography he was an associate editor. He also

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geologist; Frank Carney, Denison University; William Lockhead, Ontario Agricultural College; G. D. Hubbard, Oberlin College; M. T. Iorns, University of Texas; F. V. Emerson, University of Louisiana; J. O. Martin, U. S. Bureau of Soils; G. C. Matson, U. S. Geological Survey; Lawrence Martin, University of Wisconsin; F. S. Mills, geologist; W. E. McCourt, Washington University; Mr. Marvin, of Peary's North Pole party; F. N. Meeker, U. S. Bureau of Soils; C. L. Mills, U. S. Weather Bureau; E. M. Kindle, Canadian Geological Survey; J. L. Rich, University of Illinois; R. P. Tarr, Northern Pacific Railway; O. D. von Engeln, Cornell University; T. L. Watson, University of Virginia; R. H. Whitbeck, University of Wisconsin.

contributed to Johnson's Encyclopedia, the International Encyclopedia and to the last edition of the Encyclopedia Britannica.

Professor Tarr was a fellow of the Geological Society of America, a constituent member of the Association of American Geographers, a member of the Sigma Xi, of the Seismological Society of America, and a foreign correspondent of the Geological Society of London. He served on the International Glacial Committee and shortly before his death was elected a corresponding member of the Royal Geographical Society of Vienna. The news of this recognition was not received until he had passed away.

To the Association of American Geographers he gave loyal and unfailing service. He was a Councillor for two terms and served as first vice-president in 1907. In this year, following the death of Professor Heilprin, he was acting president and presided at the Chicago meeting. At the same time, owing to the absence of the Secretary, he performed the duties of that office also for several weeks during the preparation of the program. He presented papers with great regularity and attended every meeting except that of 1909, when he was absent in Europe. It is fresh in our memory that he was President of the Association in 1911.

His career was strengthened by a happy home life. It was tempered by sorrows in the loss of two of his four children, but dominated by good cheer. Success did not elate him, for he modestly made each stage of life the platform for new achievements.

His body rests in a little cemetery upon the terrace of an elevated delta of one of the former glacial lakes which preceded Lake Cayuga. His grave is fittingly marked by a glacial boulder, a striated erratic of granite, transported long ago from Labrador or the Adirondacks by the continental glacier and thus made ready to mark forever the resting place of one who worked long and well to interpret the records of glacial action.

After all, it is his personality which we miss most and honor most. Possessed by powerful early impulse, with purpose vaguely defined, he entered every avenue that opened in the great field and at last found the broad highway for his steps. Mental turmoil and financial struggle he compelled to an issue in clear purpose and in material and intellectual triumph. His basal quality was sincerity. He was fairness personified. He was incapable of envy or of any mean motive or act. He had profound contempt for indirectness and lived in broad charity. He would not make a harsh utterance in the face of personal injury, yet he was capable of blazing indignation and of withering contempt for all that was beneath the standards of a man. To all who loved him, and they are many, the loss is irreparable, but memory is fragrant and the heritage of his life is permanent.

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# MEMOIR OF ABBOTT LAWRENCE ROTCH

ROBERT DE COURCY WARD

Abbott Lawrence Rotch was born in Boston, January 6, 1861. He was graduated from the Massachusetts Institute of Technology (S.B.) in 1884. From 1888 to 1891, and again from 1902 to 1906, he held the appointment of assistant in meteorology at Harvard, a position which involved no teaching and in which no salary was paid. In 1906 he was appointed professor of meteorology, an honor which he prized very highly, and which gave him the position on the teaching staff of the university to which he was in every way fully entitled. He was the first professor of meteorology who has occupied that position at Harvard, and he served in this professorship without pay.

In the year 1908-09 he generously put the splendid instrumental equipment and library of Blue Hill Observatory at the service of the university, by offering a research course to students who were competent to carry on investigations in advanced meteorology. This gave Harvard a position wholly unique among the universities of the United States. To his work as instructor Professor Rotch gladly gave of his time and of his means. He fully realized the unusual advantages which he was enabled to offer those students who were devoting themselves to the science of meteorology, and the experience of the men who had the privilege of his advice and help in the work at Blue Hill shows clearly how much they profited by this opportunity. Only a short time before his death he had expressed the wish to bring about a still closer connection, for purposes of instruction, between the university and Blue Hill Observatory.

While thus planning still further usefulness for his observatory; in the midst of a life singularly active, Professor Rotch died suddenly in Boston on April 7, 1912, in the fifty-second year of his age.

Professor Rotch early developed that absorbing interest in meteorology which caused him to devote his life to the advancement of that science. Realizing the need of an institution which could be devoted to the collection of meteorological observations, and to meteorological research, free from any entanglements, he established, in 1885, Blue Hill Observatory. This observatory he not only equipped and maintained until his death, but he made provision in his will for having the work there carried on without a break. Blue Hill Observatory is to-day one of the few private meteorological observatories in the world, and there is not one which is better equipped. In fact, it is

probably safe to say that there is no private scientific establishment which is better known for the high standard of its work. The Blue Hill Observatory was, with one exception, the first in this country to be equipped with self-recording instruments, and it is to-day one of the comparatively few in the world where nearly every meteorological element is continuously recorded.

It was one of Professor Rotch's most striking characteristics that he never neglected any opportunity which might help him to keep his observatory not only abreast of the times but ahead of the times. He thought nothing of the time and the expense of taking a trip to Europe in order to attend some scientific meeting, if he believed, as he most firmly did, that he might by so doing gain inspiration and new ideas. Few scientific men are so regular in their attendance at congresses and meetings; few contribute so much that is new, or gain as much inspiration as he did at such gatherings. The list of scientific bodies of which he was a member is a long one, but every one of them gained much from his membership and from his presence at its meetings. He was regular in his attendance; ready to contribute papers; modest in his estimate of the importance of his own work; generous in his appreciation of the work of others; always ready with a word of sympathy, or encouragement, or fellowship.

We, of the Association of American Geographers, owe him much. A year ago he was with us, a helpful, energetic, enthusiastic fellow-worker. To-day his place is vacant. We miss his cheering presence, his active coöperation, his unflagging interest.

The productivity of his observatory has been remarkable. The study of cloud heights, velocities, movements, and methods of formation, at Blue Hill, was one of the most complete investigations of the kind ever undertaken. The first series of measurements in America of the height and velocity of clouds, by trigonometrical and other methods, was made at Blue Hill in 1890-91.

It was at Blue Hill that the modern methods of sounding the air by means of self-recording instruments lifted by kites were first developed and effectively put into practise (1894).

It was Rotch who, in 1901, during a voyage across the Atlantic, first obtained meteorological observations by means of kites flown from the deck of a moving steamer, thus indicating the feasibility of a new way of securing information concerning the conditions of the free air over oceans and lakes. It was Rotch who, in 1904, secured the first meteorological observations by means of sounding balloons from heights of 5 to 10 miles over the American continent. In 1905-06 he joined his colleague, Teisserenc de Bort, in fitting out and taking part in an expedition to explore the tropical atmosphere over the Atlantic Ocean by means of kites and pilot balloons, an undertaking

which resulted in the collection of important data regarding the temperatures and movements of the upper air, and especially concerning the existence of the anti-trades. But Rotch was not content with sending up kites and balloons. His enthusiasm in the study of the free air, and his desire to visit the mountain observatories of the world, led him to become a mountain climber of no mean ability. He ascended to the summit of Mont Blanc at least five times, and in South America and elsewhere he himself made meteorological observations at considerable altitudes on mountains, and carefully observed the physiological effects of the diminished pressure. He also took part in several balloon ascents. He was a member of more than one solar eclipse expedition. His studies of eclipse meteorology are among the most complete which have been made. Among his many contributions to the advancement of meteorology must also be mentioned his invention of an instrument for determining the true direction and velocity of the wind at sea.

Professor Rotch was naturally intensely interested in the recent rapid development of aeronautics. His earlier training, and his untiring zeal in the exploration of the upper air, combined to give him this interest. He turned his attention largely in that direction of late years. It was characteristic of him that, not content with the mere collection of data, and with investigations of theoretical interest, he always strove to make these results of practical use. Thus, soon after the establishment of his observatory, the issue of local weather forecasts was begun, and one of the last things which he published (in association with Mr. A. H. Palmer) was a set of "Charts of the Atmosphere for Aeronauts and Aviators" (1911), a pioneer work, embodying many of the results of observations made at Blue Hill in a practical form for the use of airmen.

Professor Rotch's list of published papers and books comprises 183 titles. These cover a wide range of subjects, by no means strictly confined to meteorology, and show most emphatically how varied were their author's interests; how extended was his reading; how alert and progressive he was in all he undertook. These 183 titles in themselves furnish a satisfactory outline of the development of meteorological science during the past 25 years. In addition to the "Charts of the Atmosphere" just referred to, he published two other books, "Sounding the Ocean of Air," (1900) and "The Conquest of the Air" (1909).

He was a pioneer who blazed new trails in a new science; an investigator, whose name is known wherever meteorological work is done; a loyal teacher who served without salary; a generous benefactor who left to the university an enduring monument of his enthusiasm and untiring devotion to the science which he himself did so much

to advance. His life and labor have been an inspiration to his scientific colleagues everywhere, but especially to those who were most closely associated with him in the work of his observatory, and in the department of the university of whose staff he was a valued member.

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# MEMOIR OF W J McGEE

N. H. DARTON

In the death of W J McGee science has been deprived of one of its most efficient workers, and mankind has lost a vigorous champion for its advancement. Had he been spared he might have had many more years of continued usefulness for he was only 59 years of age and in most respects was in fine physical and mental condition. McGee had always been a worker. He was remarkable for the universality of his interests. He was wonderfully rich in ideas, pertaining not alone to those sciences in which personally he was most interested, but also to the broader fields of general culture in which his companions might be working. A man of enthusiastic endeavor himself, he was bound to inspire enthusiasm in an honest worker in any field.

He achieved distinction in several lines of scientific work, and as an illustration of his versatility I might mention that he had a large share in the great conservation movement and was one of the principal advisors of the National Conservation Committee.

He was born on a farm in Dubuque County, Iowa, April 17th, 1853, of Irish parentage. Excepting a short attendance at the county school he was entirely self-educated. As a boy he had much to do on the farm but gave all spare time to study, and at the age of 20 had acquired the more important lines of information usually presented in schools and colleges, and had mastered sufficient law to practice in the justice's courts of his country. With some instruction from a blacksmith he became skilled in metal working mainly for the purpose of making certain agricultural implements which he invented. He also learned land surveying and at the age of 22 or 23 he began studying geology. He became so deeply engrossed with this science that he soon gave most of his time to it. It was at this period that he commenced his elaborate investigation of the superficial geology of northeastern Iowa and the preparation of the topographic base for his observations there was his first geographic work. The maps and report were finally published by the U. S. Geological Survey.

McGee's first work for the Government was on the building stones of Iowa for the 10th Census and his report was of notable excellence. From 1882 to 1893 he was geologist on the U. S. Geological Survey and during these 11 years his life was one of great activity in scien-

tific work. He traveled extensively in field work, wrote voluminously and was in close association with Director Powell in the development and administration of the survey. A summary of this work written by himself when he left the Survey and published in the 14th annual report, shows the extent and variety of his occupations in the 11 years of service. Of course it does not indicate his very great zeal and usefulness which were of incalculable value at that stage of the survey's development.

His first assignment was to assist Russell in the Lake Lahontan investigation in which he proved highly efficient. He went to Washington City in 1883 and Powell, quickly recognizing his ability, kept him there for much of the time in the following years to assist in administrative matters. He aided in perfecting cartographic methods, served on the Correlation Board and gave much attention to the classification of data available for the use of the survey. He compiled maps and reports, started the dictionary of formation names and the thesaurus of American formations, and represented the Survey at the Berlin meeting of the International Geological Congress. In connection with his study of cartographic methods McGee prepared a number of geologic maps largely for the purpose of illustrating the Survey scheme which were very useful compilations. The first of these was the geological map of the United States prepared with the assistance of Professor C. H. Hitchcock and published in 1885 in the 5th annual report. It was on the scale of 100 miles to the inch and very beautifully executed. Another edition of this map incorporating results of a large amount of new field work was issued in 1894 in part 2 of the 14th annual report.

It was McGee's instigation and zeal that led to the preparation of the large geological map of the state of New York which was the first one published since 1844. In the first stage of this work McGee and Hall made a compilation of the geology but the base was poor and the information that could be placed on the map was so fragmentary and indefinite as to location that the result was useless. With authority from the Director of the U. S. Geological Survey a new base was compiled from county maps and the writer was transferred to the state work for parts of two seasons to map boundaries and piece together the work of local observers. The map was finally published by the U. S. Geological Survey in coöperation with the state. In the course of this work I heard from James Hall warm praise of McGee's phenomenal keenness as an observer and his great ability to grasp the problems presented.

Early in his connection with the Geological Survey McGee was placed in charge of the Potomac Division of Geology which was created to study the region contiguous to the basin of Potomac River

but which was finally extended to comprise all of the middle and southern Atlantic coast province. He accomplished considerable field work himself in many portions of this area and directed the operations of a number of other investigators. Among the latter were Dr. G. H. Williams on the crystalline rocks of the Piedmont slope, Dr. J. A. Holmes, Dr. W. B. Clark, R. H. Loughridge and N. H. Darton on the Mesozoic and Cenozoic geology of the Atlantic coastal plain and Dr. E. A. Smith, L. C. Johnson and Dr. E. W. Hilgard on the formations of the Gulf region and Mississippi embayment. He also had charge of work by Hay in Kansas and of Dr. Phinney's investigation of the gas in Indiana. At the time of the Charlestown earthquake McGee was sent at once to the scene of the disaster and he obtained a large number of data used later by Dutton in his report.

McGee's principal fields of personal investigation in geology were northeastern Iowa and the Atlantic and Gulf Coastal plain. He also assisted Russell in the Lake Lahontan work and made a survey of part of Macon County, Missouri. His work in northeastern Iowa which covered an area of 20,000 square miles was done privately as already stated, before he became a member of the Geological Survey, although some supplemental work and the publication of the report were at government expense. In the Coastal Plain his observations were mainly from Maryland southward and while some of the minor details of the classification and identification of deposits may not be verified at every point, the differentiation of the Potomac, Lafayette and Columbia formations was one of the most important geologic contributions we have had. It matters but little whether or not the type locality of the Lafayette proves to be valid and that some marginal red sands are Eocene, for McGee made a master stroke in recognizing the fact that the coastal plain is covered by a wide spread mantle of littoral deposits representing Pliocene time. It was recognized over an area of 300,000 square miles and was of greatest significance in the history of the continent. McGee's first name for this formation was the Appomattox and its correlation with Lafayette was a later idea. When I began my association with McGee this formation had not been recognized north of the James River, but I found that it extended across Virginia and Maryland and some outliers remained in New Jersey. The Potomac formation has proven to comprise a group of stratigraphic units varying in range in different regions, but widely separated from the Newark group below and from the marine Cretaceous above. It included the deposit which I separated later as Magothy formation but aside from this it remains as a distinct group.

The recognition of the Columbia formation was of great significance to geography as well as to geology. It was correlated with the

earlier glacial deposits and found to cover nearly 150,000 square miles of the coastal plain. Its topography and components have most important bearing on the physiographic conditions of the early Pleistocene time in the region south of the glacier.

For many years I was intimately associated with McGee in the Geological Survey under Powell and I wish I could pay an adequate tribute to the value of his influence to me and to many other associates in those early days of the organization. He had marvelous ability to appreciate all bearings of an investigation and to make far reaching and important suggestions. His willingness to assist in guiding the policy and conduct of all lines of the survey work made him a most important member of the organization in those days. This was fully appreciated by Major Powell who brought McGee into intimate association in all administrative matters, and his genius had much to do with shaping Survey methods. He came a close personal friend of the Major's and the two spent much time together.

McGee left the survey with Major Powell at the time when the Major turned the great bureau over to the directorship of Mr. Walcott. McGee then became Powell's Chief Ethnologist in the Bureau of Ethnology, a position which opened up to him lines of investigation which were very congenial. On the death of Major Powell, in 1902, McGee continued with the bureau as acting director, but in July, 1903, on account of disagreement with S. P. Langley, Secretary of the Smithsonian, he severed his connection. This was generally regarded as a most unfortunate circumstance as undoubtedly McGee would have accomplished a very large amount of ethnological work of greatest interest and value if he had continued as director of the bureau. However, he left to accept the position of chief of the Department of Anthropology at the St. Louis Exposition where he had opportunity to make a brilliant record for administrative ability. At this exposition he presented to the public a greater variety of natives of many parts of the world than had ever been assembled before, and illustrated their natural environments, customs and products in a most instructive manner. It was one of the greatest lessons in geography that has ever been given and one that had the largest audience. When the great fair was over McGee was placed in charge of the St. Louis Public Museum project where he continued for two years till 1907, when he resigned to take up work in the Department of Agriculture as expert in charge of Soil Water investigation. This position he held until his death.

McGee made many valuable contributions to geography. In the Great Basin work he investigated the cause of the peculiar curvature of lateral moraines issuing from gorges into broad valley bottoms, some conditions of erosion by glacial ice especially in the develop-

ment of cirques, rock basins and U shaped canyons, and the law of foothill development in that region. In his study of northeastern Iowa he ascertained the conditions under which certain drift features were developed and set forth a method of determining direction of the ice flow without dependency on glacial striae. In this work also he set forth a law of land profiles applied in the driftless area, and a law of varigradation in the stream gradients. In his work on the Atlantic Coastal Plain McGee added many notable ideas to our growing science of Geomorphy, then in its infancy. He showed that geologic history could be read from topographic forms and this means was extensively used by him and by myself in unraveling the coastal plain geology. Another important mode of recognizing the formations was developed at the same time and that was by homogeny or correlation by identity of genesis . This criterion was very essential where fossils were lacking. One very important phase of this work was in the differentiation of terrace deposits and correlation of terraces which represented the same stage in the topographic development of a region. It was by this means that I mapped many areas of Lafayette and earlier Columbia deposits as well as non-fossiliferous outliers of underlying Tertiary and Cretaceous deposits. Some of these lines of work led McGee to develop a classification of geographic forms by genesis which was set forth in a paper published in the first number of the *National Geographic Magazine*. McGee's observations in lower California on his trips to Seriland and Tiberon Island afforded some very instructive facts regarding erosion conditions in arid lands. He found that sheet flood erosion was an important factor in levelling the surface and producing peneplains at various elevations above the sea. This idea has proven to be a very valuable one and has greatly simplified our conception of the topographic development of certain regions.

The paper entitled "Outlines of Hydrology" which McGee presented to the Geological Society of America in 1907 was a very valuable contribution to geography. It was a philosophic presentation of the rôle of water in nature and summarized in compact form a large amount of information. His paper on potable waters of the eastern United States published in the 14th Annual Report of the Survey was a notably complete and instructive presentation of domestic water problems. This publication was in great demand and undoubtedly had a wide influence on the development of water supplies and in guarding them from pollution. Throughout his work on the U. S. Geological Survey and later, he gave special attention to relations between geology and soils and especially the waste of soil by erosion. A large memoir on this latter subject was issued by the Department of Agriculture in 1911. It treated not only of

the conditions of soil erosion but suggested remedies which may prevent erosion and reclaim farm lands that are being damaged by it. There is now in press in that Department another publication, "Wells and Subsoil Waters," finished just before his death.

McGee always had great interest in earth crust movements and in 1894 he presented to the Geological Society a very suggestive memoir entitled "Th Extension of Uniformitarianism to Deformation." In this contribution he reviewed the criteria relating to such movements and discussed the conditions causing deformations of various kinds.

McGee gave considerable attention to Dutton's law of isostacy and showed that isostatic adjustment while sufficing to explain minor crustal oscillation is insufficient to explain the greater movements of the earth's crust. He set forth some criteria for the discrimination of two primary classes of earth movement, antecedent and consequent. In his memoir on the Gulf of Mexico as a measure of isostacy in 1892 McGee reviewed the evidences of subsidence in the Gulf region especially as indicating that the land and sea are in a state of hydrostatic equilibrium. Evidence was presented showing that in former times, however, some of the movements were cataclysmic.

Largely in connection with his work in the Bureau of Ethnology McGee achieved great distinction in Anthropology. He made many contributions to that science and devoted much time to its societies and other interests. He was president of both the American and Washington societies and was editor and contributor to the section on Anthropology in the International Encyclopedia. He was U. S. Commissioner in the International Commission of Archaeology and Ethnology, and in 1904 he was senior speaker in the World's Congress of Arts and Sciences. One of his most notable pieces of work while on the Bureau of Ethnology was an exploration of Tiburon Island in the Gulf of California. This island is inhabited by savages who had never been investigated before and the expedition which was a highly perilous one, afforded a large number of interesting and novel data. Another important item of his work in Anthropology was the formulation of principles relating to geologic evidence of human antiquity.

Probably McGee's most notable service to humanity was the prominent part which he had in the great movement for the conservation of our natural resources. He was one of the fathers of this movement and exerted very powerful influence in its growth and promulgation. He also furnished a large amount of useful data especially in the hydrographic line. He was a most prominent member of the Conservation Association and his council was always of greatest service to that body. He was chief promoter of the project of having the

great conference of governors which President Roosevelt brought to the White House in 1908. He was secretary of the conference, guided its deliberations and prepared the fine volume of its proceedings. He was made a member of the Inland Waterways Commission when it was created in 1907 and later was appointed its secretary, an office in which he continued to the time of his death. He did a vast amount of work for that commission and much of its value came from his services.

McGee was greatly interested in our scientific societies and had a prominent part in their organization, meetings and administration. He was a member and frequent attendant at all the societies in Washington and the Historical Society owes its existence largely to his interest and energy. The National Geographical Society also had his aid in its inception and development and he edited its magazine for several years. After his active editorship ceased he remained an associate editor until 1908. He was president of the society in 1904 and 1905 and held other offices in its administration.

He was greatly interested in the Anthropological Society of Washington, serving as its president, and in 1911 he was also president of the American Anthropological Society. In 1902 he was vice-president of the Archeological Institute. He was one of the founders of the Geological Society of Washington and made many communications to it in its early days. He was one of the small group of geologists who organized the Geological Society of America and for many years he was editor of its Bulletin. This publication had many novel and admirable departures from old time methods and its form was copied by various other societies. In the earlier years of its existence he attended all the meetings of the Geological Society of America and frequently read papers. He was one of the original members of the Association of American Geographers and gave us two interesting communications at the New York meeting in 1906. In 1904 McGee was chairman of the organizing committee for the International Geographical Congress and he was appointed U. S. Commissioner to the International Committee of Archeology and Ethnology and senior speaker at the World's Congress of Arts and Sciences. He was given the degree of LL.D. by Cornell College in Iowa, in 1904.

McGee died at the Cosmos Club in Washington on September 4th, 1912 from cancer which began developing in the prostate region some years ago. The progression of the final stage of the disease was slow, confining him to his room and then to bed for about two weeks, and there were four days of coma at the end.

With characteristic originality and desire to advance science, McGee willed his body to the surgeons of Jefferson Medical College of Pennsyl-

vania and his brain to Dr. Spitzka. After the simple burial service at the home of his close friend, Gifford Pinchot, the body was shipped to Philadelphia in compliance with the will. At the same time there was forwarded to Dr. Spitzka the brain of Major Powell which had been in McGee's possession since 1903. There had been some good natured rivalry between the two as to the greater weight of brain; while McGee's brain weighed 1,410 grains Powell's was 1,488 grains, both far above the average of men in general but in the case of McGee slightly below the average of the brains of 100 eminent men in Dr. Spitzka's possession.

I shall not present a list of publications made by McGee for they can be found in the bibliographies of geology. They number more than 300. His most voluminous reports were on the "Lafayette Formation," "The Geology of the Head of Chesapeake Bay," "The Pleistocene Geology of Northeastern Iowa," "Potable Waters of the Eastern United States," "Siouan Indians," "Seri Indians," "Primitive Numbers," "Soil Erosion," "Outlines of Hydrology," "Primitive Trephining in Peru."

Of the personal side of McGee I need say but little. He was kind, gentle, generous and inspiring. His efforts were all for the best results and he strove unselfishly for the truth and the advancement of science. His mind was lofty and had a deep insight into the beauty of nature. His friendship was a never-ending fountain of help, good cheer and inspiration.

# TITLES AND ABSTRACTS OF PAPERS

## New Haven, 1912

Cyrus C. Adams.

Geographical Book Reviewing.

A summary of the writer's experience as to the varieties of comment that are most valuable in reviews of geographical works; with some remarks on occasional tendencies of reviewing that are not to be encouraged.

Henry G. Bryant.

A Canoe Journey in Southeastern Labrador.

Labrador, with its large unexplored areas and comparative accessibility, presents an attractive field for the pioneer explorer. The Atlantic seaboard is desolate owing to climatic conditions produced by the Labrador current.

The interior presents much more genial conditions and the timber and mineral resources are destined to attract increasing attention. The writer's third visit was made last summer (June-September) when he ascended the St. Augustine River 141 miles from the Gulf of St. Lawrence to Lynx Lake, its source on the Height of Land. Interesting tribe of Mountaineer Indians encountered at mouth of river. After much difficulty two Indian guides secured.

With experienced topographer, two Newfoundland canoemen and the natives referred to, party started in canoes up the river on July 12th. A river flowing in a narrow valley between ridges of Archaean rocks. Uniformity of sky line owing to glacial action. Difficulties of river travel increased, by desertion of Indians and physical disability of one of the canoemen. A ten mile portage. Difficulty of locating Indian route of travel. Source of river reached. Compelled to turn back here owing to continued illness of canoeman, when within ten days of the waters of Hamilton Inlet, the objective point of journey.

Results of journey: Considerable information regarding the topography and resources of a region previously unvisited by white men. Resulting map secured by prismatic compass survey checked by astronomical observations at twenty-one stations—is submitted as a definite, if modest contribution to knowledge.

W. M. Davis.

The Development of River Meanders.—Printed in full herewith.

James Walter Goldthwait.

Remnants of a Peneplain in the White Mountains of New Hampshire.

The well developed peneplain of southern New England, which is so extensively preserved on the uplands of Connecticut and Massachusetts, has never been traced northward far into New Hampshire and Vermont. Casual observations from this field have led to the inference that the old graded surface, here, was so much less completely reduced during the period of baseleveling, and so much more extensively and deeply carved away by rivers and by the ice sheet after its uplift that it is almost impossible to identify it.

While engaged in a study of the glaciation of the Presidential Range of the White Mountains, last summer, the writer found conspicuous fragments of a subdued mountain topography on the crest of this range. It seems very probable that this well graded surface represents the imperfectly worn down interior of the ancient peneplain which in Massachusetts and Connecticut is more fully developed. The smooth slopes of this old mountain form are contrasted with the bold outlines of the deep glaciated ravines in the sides of the range.

The probability that other remnants of this ancient graded surface will be found in other parts of northern New England was briefly discussed.

Douglas W. Johnson.

The Shoreline of Cascumpeque Harbor, Prince Edward Island.

The shoreline of Cascumpeque Harbor illustrates in an admirable manner certain features normally produced by the submergence of a maturely dissected plain, and presents additional phenomena which have caused it to be cited as the best example of recent submergence of a maturely dissected plain in the Maritime Provinces. The characteristics of the shoreline were briefly described, and the phenomena attributed to coastal subsidence were discussed. It was shown that forests have been killed by a local rise in high tide level, due to a change in the form of the shoreline, and to normal retrograding of an exposed shore under wave attack; that the remarkable Black Bank peat deposit affords no evidence of coastal subsidence; and that other evidence is more in accord with the theory of long-continued coastal stability.

Lawrence Martin.

The Filling of Fiords in Alaska.—Read by Title.

Subsequent to their excavation by glacial erosion a number of Alaskan fiords have been partly or wholly filled with glacial deposits. The nature of the glacial filling varies considerably along the following lines:—(a) submerged moraines, (b) delta building from the

side, (c) delta building at the head, (d) marine alongshore deposits supplied by distant glacial rivers, and (e) widespread bottom deposits.

The extent of this filling reaches 75 to 150 square miles in some fiords, as at Orca Inlet in Prince William Sound and at the head of Chilkat Inlet in southeastern Alaska. The thickness of such deposits which rise to or above sea level, amounts to at least 600 feet as near Katsehin River in Lynn Canal, in Orca Bay, Prince William Sound, and along Bering River near Controller Bay.

Of the several deposits, the submerged moraines, or moraine bars, are typically illustrated in Unakwik Inlet, Blackstone Bay, and Harriman Fiord in Prince William Sound, and in southern Russell Fiord in Yakutat Bay. The lateral deltas are well seen at the Stikine River in southeastern Alaska, the Katsehin River in Lynn Canal, and the Bering, Gandil, Nichawak, and Edwardes rivers in Controller Bay. The deltas and valley trains of outwash gravels at the heads of fiords are found at such places as Lowe and glacier rivers in Port Valdez, the streams from Mendenhall Glacier in Gastineau Channel, the Copper River in a former Copper River Fiord, and the Chilkat River at the head of Chilkat Inlet. The filling of fiords by tidal deltas, supplied by distant glacial streams and alongshore currents, is exemplified in Orca Bay and Orca Inlet in southeastern Prince William Sound. The widespread bottom filling of undetermined amounts of fine material carried in suspension and boulders dropped by floating icebergs is shown in Yukatat Bay, near Columbia Glacier, and in nearly all the fiords of Alaska.

Frank E. Williams (Introduced by Lawrence Martin).
Fiords of Southeastern Alaska.

The study of the fiords of southeastern Alaska has shown that the valleys have been occupied to a greater or less extent by glaciers moving in various directions, but the large ones flowed southward. While the "Inside Passage" appears to have a trend parallel to the mountain ranges, a study of the main fiord, Lynn Canal—Chatham Strait, shows that it does not coincide in direction for any great distance with the strike of the rock structure. The trend of this valley may be due to faulting, to rock structure in part, or to an inherited drainage from a former peneplained area. The fiords are preglacial valleys initiated and more or less developed by stream erosion but owe practically all of their present features to glacial actions. Much of the data for the study of the fiords was obtained from the U. S. Coast Survey Charts. The submerged contour maps based on this data show many hanging valleys, basins that have been scooped out below sea level, and some fiords whose channels continue across the continental shelf.

Isaiah Bowman.

Nivation in the Central Andes and a New Hypothesis of Cirque Development.

The physical effects of snow motion and the conditions under which motion takes place were presented. Curves were exhibited showing the bearing of these observations on the distribution of snow pressure and motion in a typical headwater alcove in the Central Andes. It is suggested that bergschrunds may be entirely absent in all stages of the glacial cycle without preventing the development of cirques.

George B. Roorbach (Introduced by W. M. Davis)

The Fault-block Topography of the Mohawk Valley.

The eastern Mohawk Valley is a type of fault-block topography developed in a region of initially south-dipping beds of sedimentary rocks overlapping resistant crystallines, that have been broken into blocks and tilted gently westward by several parallel north-south faults. Reduced in previous cycles nearly, if not quite, to peneplain conditions, the region is now occupied by the wide, mature valley of the Mohawk across which is a series of eastward facing fault-line escarpments, making the raised edges of the fault blocks. The main topographic features of one fault block are duplicated, with marked similarity, in each of the others, thus giving a series of repeating surface and drainage patterns. The fault topography has influenced, to a considerable extent, the economic conditions of the valley, especially the distribution of population, the character and distribution of soils, the distribution of forests, the location of water-power sites, etc.

W. M. Davis.

The Geographical Descriptions of the Llano-Burnet Folio of the United States Geological Survey.

The geographical introduction and the physiographic conclusion in the text of the U. S. Geological Survey Folios, taken with the topographical and geological maps, afford valuable descriptions of various parts of the United States. The inquiry is here raised as to whether the geographical introductions represent the present state of scientific geography as well as the following pages represent the present state of scientific geology. As an example for discussion the recently published Llano-Burnet folio was selected; it embraces a particularly interesting district in central Texas, regarding which an abundant knowledge has evidently been collected. Suggestions were made regarding terminology, method of presentation, and diagrammatic illustration, which, it is believed, would, if adopted, increase the high geographical value already reached in the present form of the folio.

F. E. Matthes.

Is the Delineation of Land Forms Capable of Being Rationalized? —Read by Title.

In the topographic profession it is not generally conceded that the portrayal of land forms on maps can be systematized in accordance with definite principles. It is held to be an art in which each man works with the light and talents that are given him. As a result there is a wide divergence in the character of maps drawn by different men. Scarcely two topographers agree in style of delineation. Maps made by different nations in regions having a physiographic kinship in some instances bear but little resemblance to one another, and this is as likely to be true of modern maps as of maps made several decades ago. While methods of survey have made rapid advances during the last twenty years, the art of topographic delineation has stood still. Its results to-day are likely to be no more trustworthy as representations of the relief than the topographic work of the last century. Considering that the delineation of land forms is by far the most costly part of the making of an original map, the desirability of progress in this direction will be plain. The problem has an economic side which alone would justify attempts at its solution.

Several years of tentative effort have strengthened the writer's conviction that there is a definite basis for a *rationale* of topographic delineation in physiographic science. While it may not be possible to eliminate entirely the personal equation in topographic work, it is believed nevertheless to be feasible to minimize the present divergencies by the recognition of certain fundamental principles.

Ellsworth Huntington.

The Shifting of Climatic Zones as Illustrated in Mexico.

In applying new tests to the theory of pulsatory changes of climate, the author last Spring made a visit to southern Mexico and Yucatan. Three types of evidence were found. In the first place excavations in the lacustrine plain surrounding the City of Mexico revealed an alternation of strata strongly suggestive of climatic pulsations. In the second place, alluvial terraces of the kind found commonly in the dry regions both of Asia and the United States are abundant in Mexico, and apparently can be explained only as the result of alternations between dry and moist periods. Finally in Yucatan a new and especially interesting line of evidence was found. Some of the chief ruins of that region are located in places where the forest is apparently too dense and luxuriant to permit of extensive habitation. This seems to indicate that in general the climate of the present is moister than that of the past, a conclusion directly contrary to that indicated in regions farther north. This seems to

suggest a shifting of climatic zones in such a way that subequatorial rains are now abundant in places lying poleward of their limit at some previous time. Such a change may be explained as a shifting of all the climatic zones from the pole toward the equator.

Alfred J. Henry (Introduced by R. DeC. Ward).

Secular Variations of Precipitation in the United States.

Owing to the vast extent of territory involved, and to the absence of actual observations of precipitation over a great portion of it, especially in the seventies and early eighties, a discussion of the secular variation of precipitation in the United States is beset by many difficulties. The Rocky Mountains evidently form a dividing line between two essentially different types of rainfall. East of the Rocky Mountains there are also several different types of precipitation. The quantity of rain or snow which falls on the areas represented by these types depends in large measure upon the varying weather conditions, and the latter in turn are subject to the control of the general atmospheric circulation. When therefore we combine in a single unit the precipitation of the whole country we reach a result that is difficult of interpretation since negative departures in one region may be offset by positive departures in another, and vice versa. Notwithstanding the foregoing, the evidence seems to point to a maximum of precipitation in the United States in the middle seventies which extended well into the eighties. The period of abundant rains was broken, however, by several years of light rainfall. Another maximum, although less pronounced, occurred between the years 1901 and 1906, the year 1903 however, being dry, and finally a third maximum occurred in 1909 only to be followed in 1910 by one of the lightest annual rainfalls recorded in the last quarter of a century. The length of the intervals between periods of light and heavy precipitation, respectively, is quite irregular. The periods themselves may be confined to a single year, or they may extend over three or four years. The general tendency, east of the Rocky Mountains in recent years, has been toward a diminished rainfall and this diminution has been much more pronounced in some districts than others. These special cases were discussed in some detail and the conclusion reached that the cause of the diminution is to be sought in the general rather than the local movements of the atmosphere.

Robert M. Brown.

Final Report of the National Waterways Commission.—Printed in full herewith.

Sumner W. Cushing.

Some Important Coastal Plains in Japan.—Printed in full herewith.

Isaiah Bowman.

Lake Titicaca and the Rivers of Tiahuanaco.

A review was given of current opinions concerning the former greater size of Lake Titicaca, and the facts upon which they are based presented. The so-called evidence of former great extent is not valid. The lake has suffered only a slight reduction and never had a connection with Lake Minchin, the great lake that once occupied the Poopo depression on the south. The physical history of the basin and relation to megalithic ruins at Tiahuanaco were outlined. A summary of the assumption as to change in lake level affecting the site of the ancient city and of the effects of climatic changes on the highland people was made. Part of climatic change is due to regional uplift.

F. V. Emerson.

The Ozark Border and its People.

The Ozark Region in Missouri is a dissected plateau consisting of a strongly dissected center, a moderately dissected plateau-like area and the border where the Ozarks merge with the western prairies. Miller County, the area described, belongs on the whole to the moderately dissected plateau region. Topographically it consists of two areas: the Osage Valley passing through the north central part has a narrow flood plain flanked on either side by deeply dissected zones, the "River Breaks," eight to fifteen miles wide; on either side of the Valley are sharply rolling areas known locally as the "Prairies."

The distribution of population, farm products and values, and, in some degree, traits of the people are influenced primarily by soil types, the means of communication being equally available for much of both areas. Practically all the soils are derived from a cherty limestone except the alluvial soils, the dominant factor in the upland soils being topography. The weathered limestone yields a silt loam containing considerable chert; on the prairies the main type is this silt loam but on the slopes the finer material is removed leaving a more or less stony loam. At the foot of the slopes is a "shoulder" of colluvial material, the soil of which is much sought after for crop purposes. The productive farms are found on the prairies, the narrow flood plains and the narrow belts of colluvial material at the foot of slopes. Between the people of the "Prairies" and "Breaks" are great differences in prosperity and noticeable differences in other directions.

Charles C. Colby (Introduced by Mark Jefferson).

Some Geographic Influences in the Development of the Minnesota Driftless Area.

The influence of topography, soil, and drainage in the location and development of farms, transportation routes, towns, and manufactur-

ing industries in the driftless area in southeastern Minnesota was presented. Especial attention was given to the factors which are causing a change in the size, products, and problems of the farms and which are forcing the people in this region to know and practice the principles of conservation. A comparison was made of the present economic conditions in the counties in this unglaciated dissected area with other counties in the glaciated undissected sections of the state.

J. Russell Smith.

Tree Crops as a Control of Erosion.

Erosion is the most serious of all resource wastes. Plowing of rolling and hilly land is the greatest promoter of erosion. We need crops that grow without plowing. Some fruit and nut-yielding trees meet this requirement. The adjustment of agriculture to resources and the preservation of the resources demand a new agriculture dependent on trees rather than on tilled grasses. This holds the possibility of doubling, or more than doubling the food supply of the United States and stopping our greatest resource waste.

F. P. Gulliver.

Chestnut and Man.—Read by Title.

Chestnut wood has been used in this country for a great variety of purposes, and its abundance in our forests has been an important factor in the rapid development of settlements along the Atlantic coast from Maine to Alabama. The ease with which the tree is felled, the great variety of uses to which the wood can be put, its rapid growth and often increased value as sprouts over seedlings, and its vigorous growth notwithstanding its susceptibility to various diseases make it of great geographic significance to man. To-day man is beginning to realize the great reduction in the cost of living from converting almost valueless sprout lands on mountain sides into great food producing areas. The Sober farm near Paxinos, Pennsylvania, with its two square miles of chestnut growths is a magnificent conservation example to the American people.

Mark Jefferson.

The Geographic Distribution of Culture in the United States.—Read by Title.

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## Explanation of Plate II

*a* General view of Osaka Bay land forms. In the foreground is the intensely cultivated young coastal plain; beyond, the wooded mature coastal plain and in the distance the even crested block mountains.

*b* From a spur of the mature coastal plain looking over the young coastal plain. An embanked aggraded consequent river is seen at the left extending across the plain. The main road is on the left embankment.

*b*

## Explanation of Plate III

*a* On a slope of the mature coastal plain looking toward the mountainous oldland. The reservoir at the left receives water from a simple consequent river and irrigates the plots on the terrace slope and young coastal plain at the right.

*b* Looking down a simple consequent valley of the mature coastal plain on the east side of Osaka Bay. The village at the right distance is on the young coastal plain. The mature coastal plain reaches the sea at the right. Both plains end in marine cliffs, one of which is shown in Plate IVa.

*a*

*b*

## Explanation of Plate IV

*a* Marine cliff at outer margin of the mature coastal plain from which clay is being taken for making porcelain. A natural spring is seen at the center of the picture. It issues from above a heavy stratum of clay.

*b* Looking across an inland stretch of the young coastal plain, on which is situated a large chimneyless village, to the mature coastal plain at the left and the back of one of the block mountains at the right.

PLATE IV



*a*

*b*

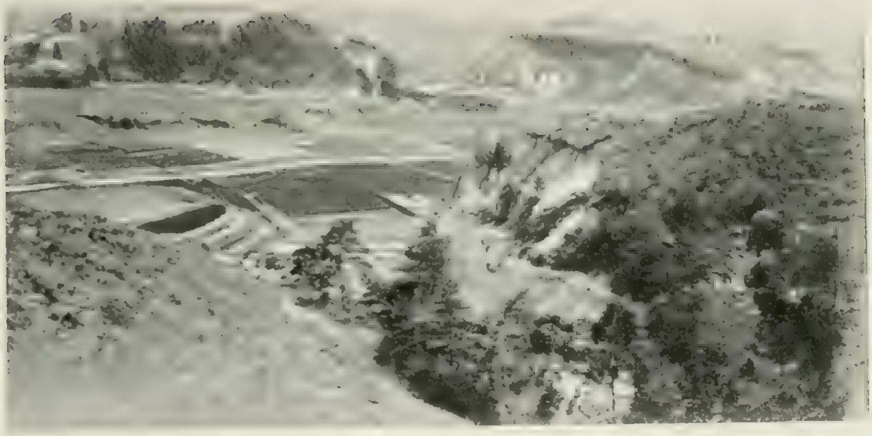
Explanation of Plate V

*a* Showing insequent dissection and lack of cultivation in the mature coastal plain spurs in the foreground and distance, in contrast with the young coastal plain below.

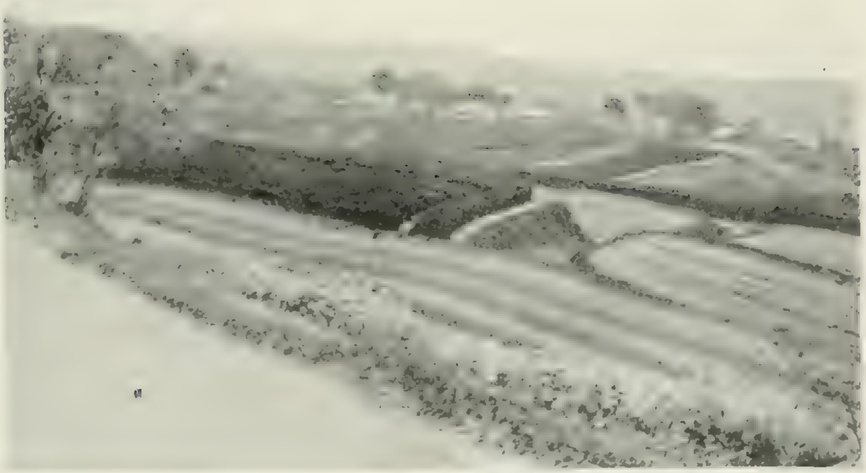
*b* Cultivated terraces in the less dissected outer portions of the fans near the inner margin northwest of Kobe.

PLATE V





*a*



*b*

Explanation of Plate VI

*a* Badland topography in the much dissected fans near Kobe.

*b* Excellent road construction and terracing in the mature coastal plain, with mountainous oldland in the distance.

*a*

*b*

Explanation of Plate VII

*a* Terracing on the mature coastal plain. At the base of the mature coastal plain fragment are caves cut in clay to serve as tool houses.

*b* Steep face of the block mountain oldland northwest of Kobe, showing the triangular facets.

a

b

## Explanation of Plate VIII

*a* From the upper surface of the mature coastal plain, looking across an extended consequent valley to a "bridge" of the mature coastal plain that connects its main body with the oldland.

*b* The young coastal plain occupied by the city of Kobe. Western influence is shown plainly in the houses in the foreground.

*a*

*b*

EXPLANATION OF PLATE IX

*a* In Kobe, looking along an exceptionally broad street, toward the block mountain oldland. Note the even mountain crest suggestive of a prefaulting peneplain.

*b* In Kobe, showing a common method of transportation on the young coastal plain.

*a*

*b*

## Explanation of Plate X

At the fall line back of Kobe, showing the Nunbiki waterfall, a tea house, and a common method of mountain transportation for passengers.

PLATE X



EXPLANATION OF PLATE XI

*a.* A typical harbor such as is at the slightly drowned mouth of many of the rivers at the outer margin of the young coastal plain. Much of it is artificial and it is only deep enough to accommodate the native junks.

*b.* A canal scene in densely populated Osaka.

*a*

*b*

## Explanation of Plate XII

*a*. A much dissected flank of the mature coastal plain. Note how painstakingly the Japanese have reformed the surface to make as much as possible highly productive, crowding the well graded road to its narrowest limits.

*b*. In Yokohama. The lower level is on the young coastal plain: the higher, on the mature coastal plain. The men's staircase, otokozaka, of one hundred steps, is here seen connecting the two.

a

b

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